CHAPTER 4

HYDROLOGIC METHODS

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

#	SECTIONS	PAGE

LIST OF ILLUSTRATIONS

#	FIGURES	PAGE

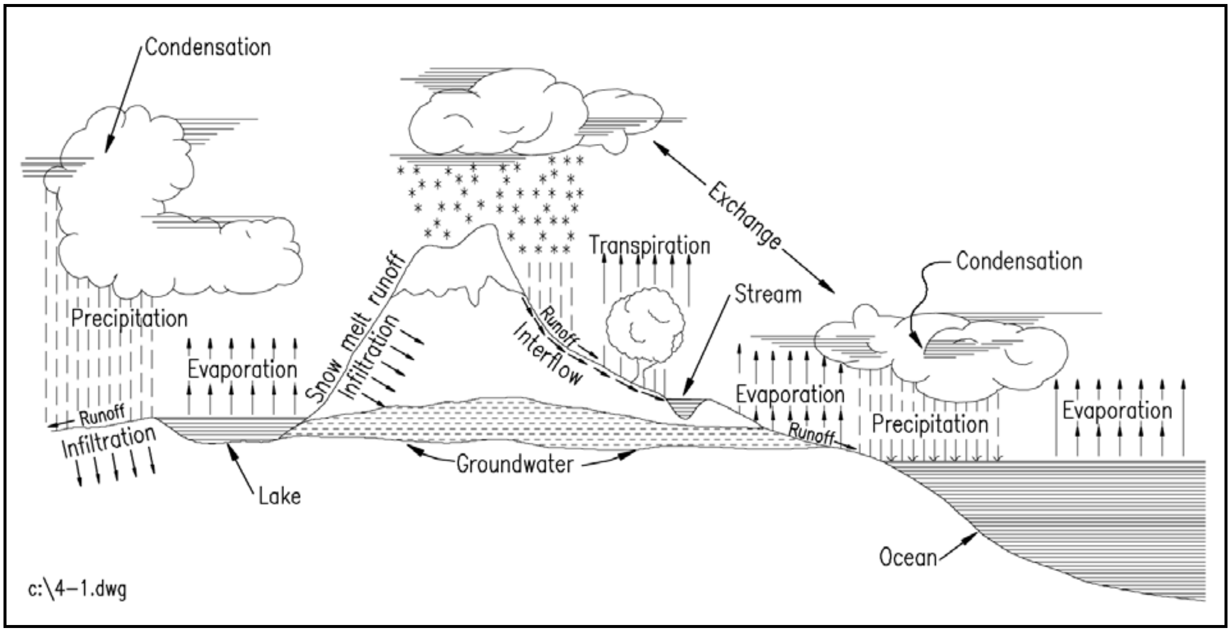
LIST OF ILLUSTRATIONS (Continued)

HYDROLOGIC METHODS

4-1 INTRODUCTION

Hydrology is the study of the properties, distribution, and effects of water on the earth's surface, and in the soils, underlying rocks, and atmosphere. The ***hydrologic cycle*** is the closed loop through which water travels as it moves from one phase, or surface, to another.

FIGURE 4 - 1
The Hydrologic Cycle



Source: Federal Highway Administration HEC No. 19

The hydrologic cycle is complex, and to simulate just a small portion of it, such as the relationship between precipitation and surface runoff, can be an inexact science. Many variables and dynamic relationships must be accounted for and, in most cases, reduced to basic assumptions. However, these simplifications and assumptions make it possible to develop solutions to the flooding, erosion, and water quality impacts associated with changes in land cover and hydrologic characteristics.

Proposed engineering solutions typically involve identifying a storm frequency as a benchmark for controlling these impacts. The 2-year, 10-year, and 100-year frequency storms have traditionally been used for hydrologic modeling, followed by an engineered solution designed to offset increased peak flow rates. The hydraulic calculations inherent in this process are dependent upon the designer’s ability to predict the amount of rainfall and its intensity. Recognizing that the frequency of a specific rainfall depth or duration is developed from a statistical analysis of historical rainfall data, the designer cannot presume to accurately predict the characteristics of a future storm event.

One could argue that the assumptions in this simulation process undermine the regulatory requirement of mitigating the adverse impacts of development on the hydrologic cycle. However, it is because of these same assumptions and uncertainties that strict adherence to an acceptable methodology is justified. Ongoing efforts to collect and translate data will help to improve the current methodology so that it evolves to more closely simulate the natural hydrologic cycle.

The purpose of this chapter is to provide guidance for preparing acceptable calculations for various elements of the hydrologic and hydraulic analysis of a watershed.

4-2 PRECIPITATION

Precipitation is a random event that cannot be predicted based on historical data. However, any given precipitation event has several distinct and independent characteristics which can be quantified as follows:

Duration - The length of time over which precipitation occurs (hours).
Depth - The amount of precipitation occurring throughout the storm duration (inches).
Frequency - The recurrence interval of events having the same duration and volume.
Intensity - The depth divided by the duration (inches per hour).

A specified amount of rainfall may occur from many different combinations of intensities and durations, as shown in **Table 4-1**. Note that the peak intensity of runoff associated with each combination will vary widely. Also, storm events with the same intensity may have significantly different volumes and durations if the specified storm frequency (2-year, 10-year, 100-year) is different, as shown in **Table 4-2**. It, therefore, becomes critical for any regulatory criteria to specify the volume (or intensity) **and** the duration for a specified frequency design storm. Although specifying one combination of volume and duration may limit the analysis, with regard to what is considered to be the critical variable for any given watershed (erosion, flooding, water quality, etc.), it does establish a baseline from which to work. (This analysis supports the SCS 24-hour design storm since an entire range of storm intensities is incorporated into the rainfall distribution.) Localities may choose to establish criteria based on specific watershed and receiving channel conditions, which will dictate the appropriate design storm. (Refer to **Channel Capacity/Channel Design** in **Chapter 5**, and MS-19 in the Virginia Erosion & Sediment Control Regulations.)

4-2.1 Frequency

The frequency of a specified design storm can be expressed either in terms of ***exceedence probability*** or ***return period***.

Exceedance Probability is the probability that an event having a specified volume and duration will be exceeded in one time period, which is most often assumed to be one year.

Return Period is the average length of time between events having the same volume and duration.

If a storm of a specified duration and volume has a 1 percent chance of occurring in any given year, then it has an exceedence probability of .01 and a return period of 100 years. The return period concept is often misunderstood in that it implies that a 100-year flood will occur only once in a 100-year period. This will not always hold true because storm events cannot be predicted deterministically. Because storm events are random, the exceedence probability indicates that there is a finite probability (.01 for this example) that the 100-year storm may occur in any given year or consecutive years, regardless of the historic occurrence of that storm event.

TABLE 4 - 1
Variations of Duration and Intensity for a Given Volume

Duration (*hr.*)	**Intensity (*in./hr.*)**	**Volume (in.)**
0.5	3.0	1.5
1.0	1.5	1.5
1.5	1.0	1.5
6.0	0.25	1.5

TABLE 4 - 2
Variations of Volume, Duration and Return Frequency for a Given Intensity

Duration (*hr.*)	**Volume (*in.*)**	**Intensity (*in./hr.*)**	**Frequency (*yr.*)**
1.0	1.5	1.5	2
2.0	3.0	1.5	10
3.0	4.5	1.5	100

4-2.2 Intensity-Duration-Frequency Curves

To establish the importance of the relationship between average intensity, duration, and frequency, the U.S. Weather Bureau compiled Intensity-Duration-Frequency (I-D-F) curves based on historic rainfall data for most localities across the country. The rational method uses the I-D-F curves directly, while SCS methods generalize the rainfall data taken from the I-D-F curves and create rainfall distributions for various regions of the country. Selected I-D-F curves for regions of Virginia are provided in the Appendix at the end of this chapter.

There is an ongoing debate concerning which combinations of storm durations and intensities are appropriate to use in a hydrologic analysis for a typical urban development. Working within the limitations of the methodology as described later in this section, small drainage areas (1 to 20 acres) in an urban setting can be accurately modeled using either SCS or rational methods. The belief that the short, very intense storm generates the greatest need for stormwater management often leads designers to use the rational method for stormwater management design, since this method is based on short duration storms. However, the SCS 24-hour storm is also appropriate for short duration storms since it includes short storm intensities within the 24-hour distribution.

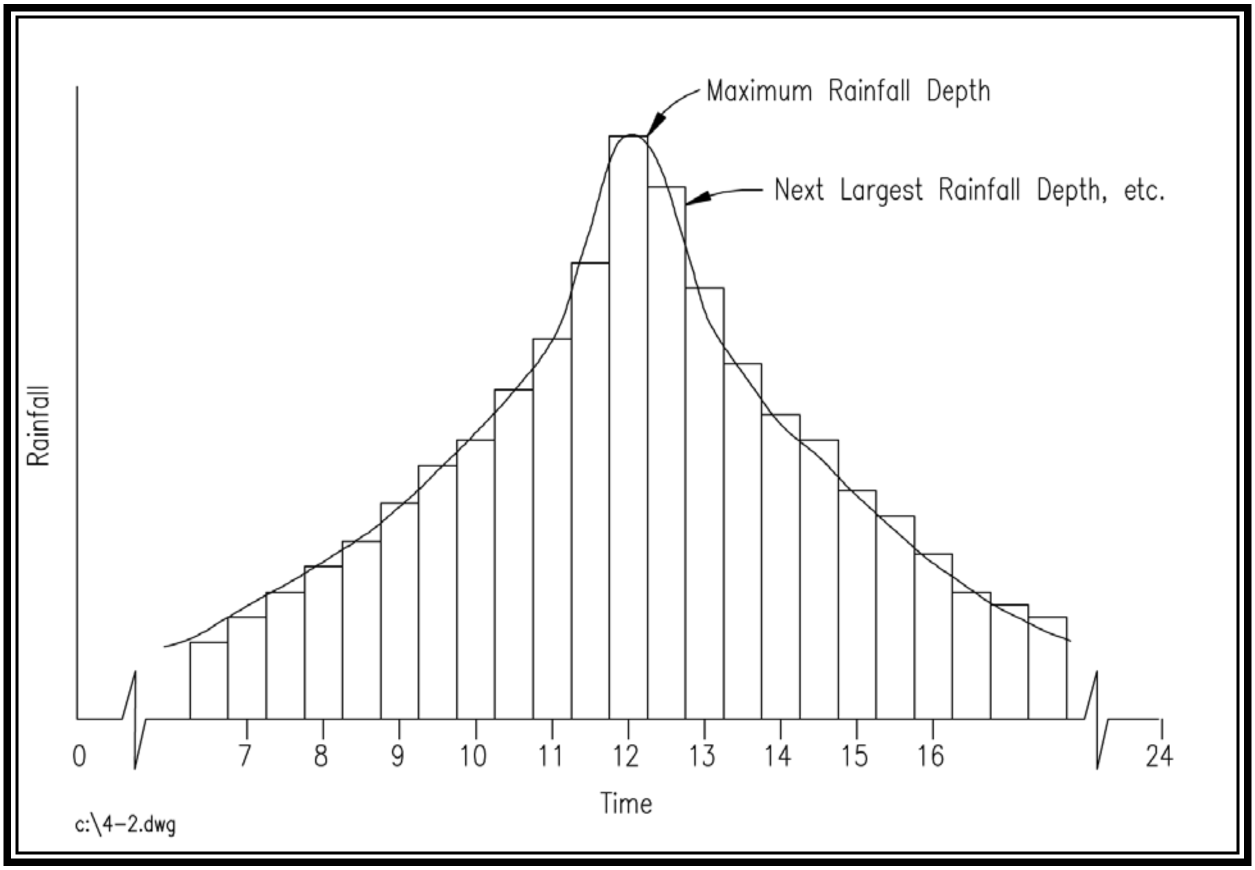
4-2.3 SCS 24-Hour Storm Distribution

The SCS 24-hour storm distribution curve was derived from the National Weather Bureau's Rainfall Frequency Atlases of compiled data for areas less than 400 square miles, for durations up to 24 hours, and for frequencies from 1 to 100 years. Data analysis resulted in four regional distributions: *TYPE I* and *IA* for use in Hawaii, Alaska, and the coastal side of the Sierra Nevada and Cascade Mountains in California, Washington, and Oregon; *TYPE II* distribution for most of the remainder of the United States; and *TYPE III* for the Gulf of Mexico and Atlantic coastal areas. The *TYPE III* distribution represents the potential impact of tropical storms which can produce large 24-hour rainfall amounts. Most of the Commonwealth of Virginia falls under the *TYPE II* distribution, while Virginia Beach is classified as *TYPE III.*

For a more detailed description of the development of dimensionless rainfall distributions, refer to the USDA Soil Conservation Service's National Engineering Handbook, Section 4 (SCS NEH).

The SCS 24-hour storm distributions are based on the generalized rainfall depth-duration-frequency relationships collected for rainfall events lasting from 30 minutes up to 24 hours. Working in 30-minute increments, the rainfall depths are arranged with the maximum rainfall depth assumed to occur in the middle of the 24-hour period. The next largest 30-minute incremental depth occurs just after the maximum depth; the third largest rainfall depth occurs just prior to the maximum depth, etcetera. This continues with each decreasing 30-minute incremental depth until the smaller increments fall at the beginning and end of the 24-hour rainfall (see **Figure 4-2**).

FIGURE 4 - 2
Typical 24-Hour Rainfall Distribution



It is important to note that this process includes all of the critical storm intensities within the 24-hour distributions. The SCS 24-hour storm distributions are, therefore, appropriate for rainfall and runoff modeling for small and large watersheds for the entire range of rainfall depths.

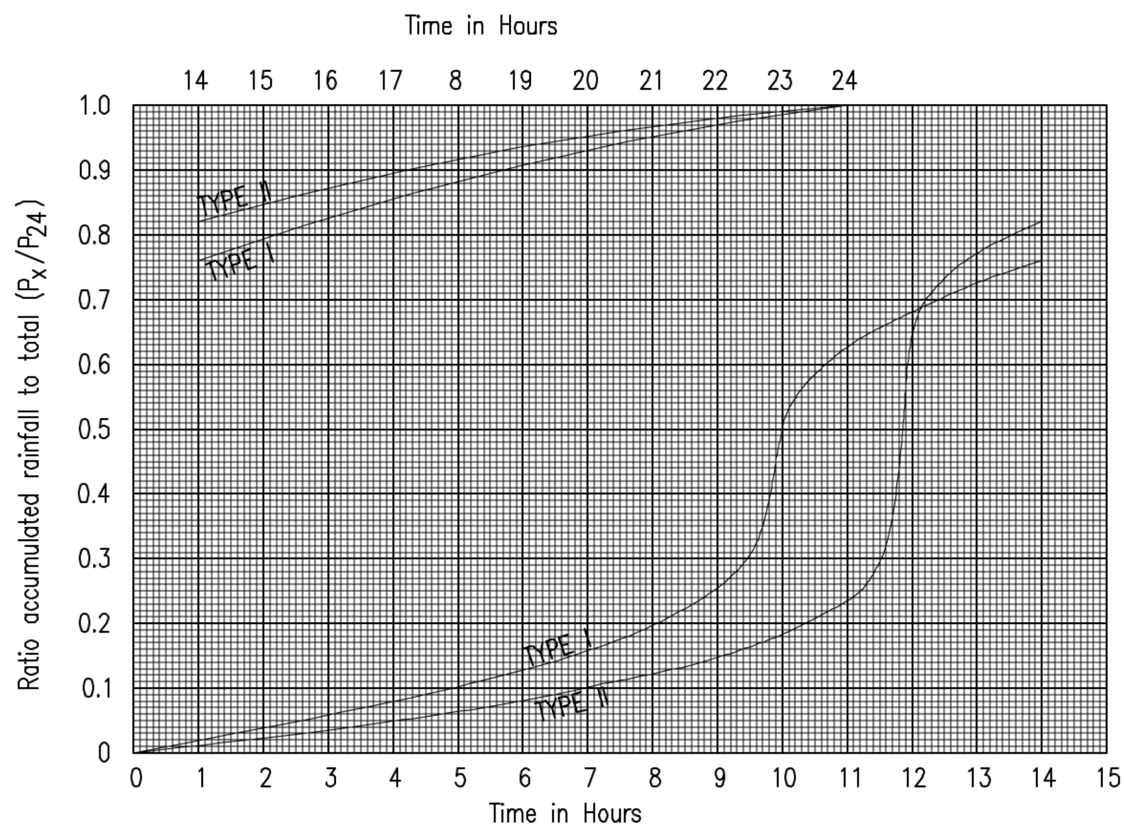
One of the stated disadvantages of using the SCS TR-55 method for hydrologic modeling is its restriction to the use of the 24-hour storm. The following discussion, taken directly from Appendix B of the TR-55 manual (U.S. Department of Agriculture, 1986) addresses this limitation:

> *"To avoid the use of a different set of rainfall intensities for each drainage area's size, a set of synthetic rainfall distributions having "nested" rainfall intensities was developed. The set "maximizes" the rainfall intensities by incorporating selected short-duration intensities within those needed for larger durations at the same probability level.*
>
> *For the size of the drainage areas for which SCS usually provides assistance, a storm period of 24 hours was chosen for the synthetic rainfall distributions. The 24-hour storm, while longer than that needed to determine peaks for these drainage areas, is appropriate for determining runoff volumes. Therefore, a single storm duration and associated synthetic rainfall distribution can be used to*

represent not only the peak discharges but also the runoff volumes for a range of drainage area sizes."

Figure 4-3 shows the SCS 24-hour rainfall distribution, which is a graph of the fraction of total rainfall at any given time, *t*. Note that the peak intensity for the *TYPE II* distribution occurs between time *t = 11.5 hours* and *t = 12.5 hours*.

FIGURE 4 - 3
SCS 24-Hour Rainfall Distribution



TYPE 1 – Coastal Side of Sierra Nevada and Cascade Mountains in California, Oregon and Washington: the Hawaiin Islands and Alaska.

TYPE II – Remaining United States, Puerto Rico and Virgin Islands.

c:\4–3.dwg

Source: USDA SCS

4-2.4 Synthetic Storms

The alternative to a given rainfall "distribution" is to input a custom design storm into the model. This can be compiled from data gathered from a single rainfall event in a particular area, or a synthetic storm created to test the response characteristics of a watershed under specific rainfall conditions. Note, however, that a single historic design storm of known frequency is inadequate for the design of flood control structures, drainage systems, etc. The preferred procedure for such design work is to synthesize data from the longest possible grouping of rainfall data and derive a frequency relationship as described with the I-D-F curves.

4-2.5 Single Event vs. Continuous Simulation Computer Models

The fundamental requirement of a stormwater management plan is a quantitative analysis of the watershed hydrology, hydraulics, and water quality, with consideration for associated facility costs. Computers have greatly reduced the time required to complete such an analysis. Computers have also greatly simplified the statistical analysis of compiled rainfall data.

In general, there are two main categories of hydrologic computer models: *single-event computer models* and *continuous-simulation models*.

Single-event computer models require a minimum of one design-storm hyetograph as input. A ***hyetograph*** is a graph of *rainfall intensity* on the vertical axis versus *time* on the horizontal axis, as shown in **Figure 4-4**. A hyetograph shows the volume of precipitation at any given time as the area beneath the curve, and the time-variation of the intensity.

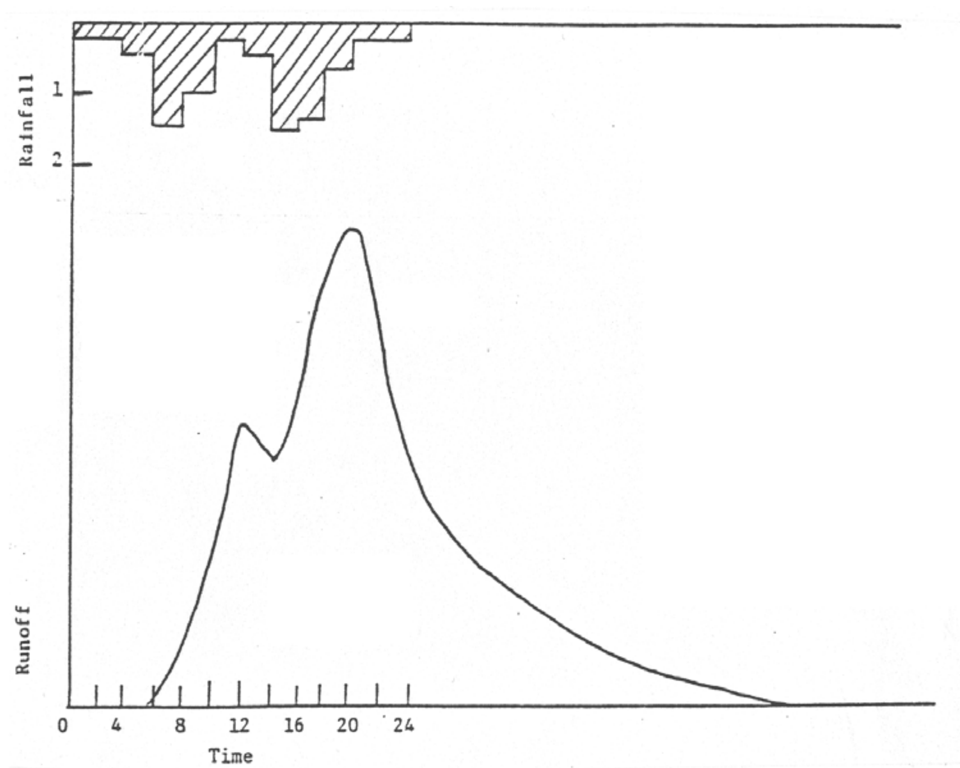
The hyetograph can be a *synthetic hyetograph* or an *historic storm hyetograph*. When a frequency or recurrence interval is specified for the input hyetograph, it is assumed that the resulting output runoff has the same recurrence interval. (This is one of the general assumptions which is made for most single-event models.)

Continuous simulation models, on the other hand, incorporate the entire meteorologic record of a watershed as their input, which may consist of decades of precipitation data. The data is processed by the computer model, producing a continuous runoff hydrograph. The continuous hydrograph output can be analyzed using basic statistical analysis techniques to provide discharge-frequency relationships, volume-frequency relationships, flow-duration relationships, etc. The extent to which the output hydrograph may be analyzed is dependent upon the input data available. The principal advantage of the continuous simulation model is that it eliminates the need to choose a design storm, instead providing long-term response data for a watershed which can then be statistically analyzed for the desired frequency storm.

Computer advances have greatly reduced the analysis time and related expenses associated with continuous models. It can be expected that future models, which combine some features of continuous modeling with the ease of single-event modeling, will offer quick and more accurate analysis procedures.

The hydrologic methods discussed in this handbook are limited to single-event methodologies, based on historic data. Further information regarding the derivation of the I-D-F curves and the SCS 24-hour rainfall distribution can be found in NEH, Section 4 - Hydrology.

FIGURE 4 - 4
Rainfall Hyetograph and Associated Runoff Hydrograph



4-3 RUNOFF HYDROGRAPHS

A ***runoff hydrograph*** is a graphical plot of the runoff or discharge from a watershed with respect to time. Runoff occurring in a watershed flows downstream in various patterns which are influenced by many factors, such as the amount and distribution of the rainfall, rate of snowmelt, stream channel hydraulics, infiltration capacity of the watershed, and others, that are difficult to define. No two flood hydrographs are alike.

Empirical relationships, however, have been developed from which complex hydrographs can be derived. The critical element of the analysis, as with any hydrologic analysis, is the accurate description of the watershed's rainfall-runoff relationship, flow paths, and flow times. From this data, runoff hydrographs can be generated.

This section provides a brief description of some of the types of hydrographs used for modeling watersheds.

Natural hydrographs obtained directly from the flow records of a gauged stream.

Synthetic hydrographs obtained by using watershed parameters and storm characteristics to simulate a natural hydrograph.

Unit hydrographs which are natural or synthetic hydrographs adjusted to represent one inch of direct runoff.

Dimensionless unit hydrographs which are made to represent many unit hydrographs by using the time to peak and the peak rates as basic units and plotting the hydrographs in ratios of these units.

4-3.1 Natural Hydrographs

Extensive watershed gauge data is required to develop a ***natural hydrograph***. Frequently, the data must be interpolated between points in order to provide a complete hydrograph. Stream gauge data is very useful for calibrating models or synthetic hydrographs. However, the lack of such data often eliminates the option of using a natural hydrograph.

4-3.2 Synthetic Hydrographs

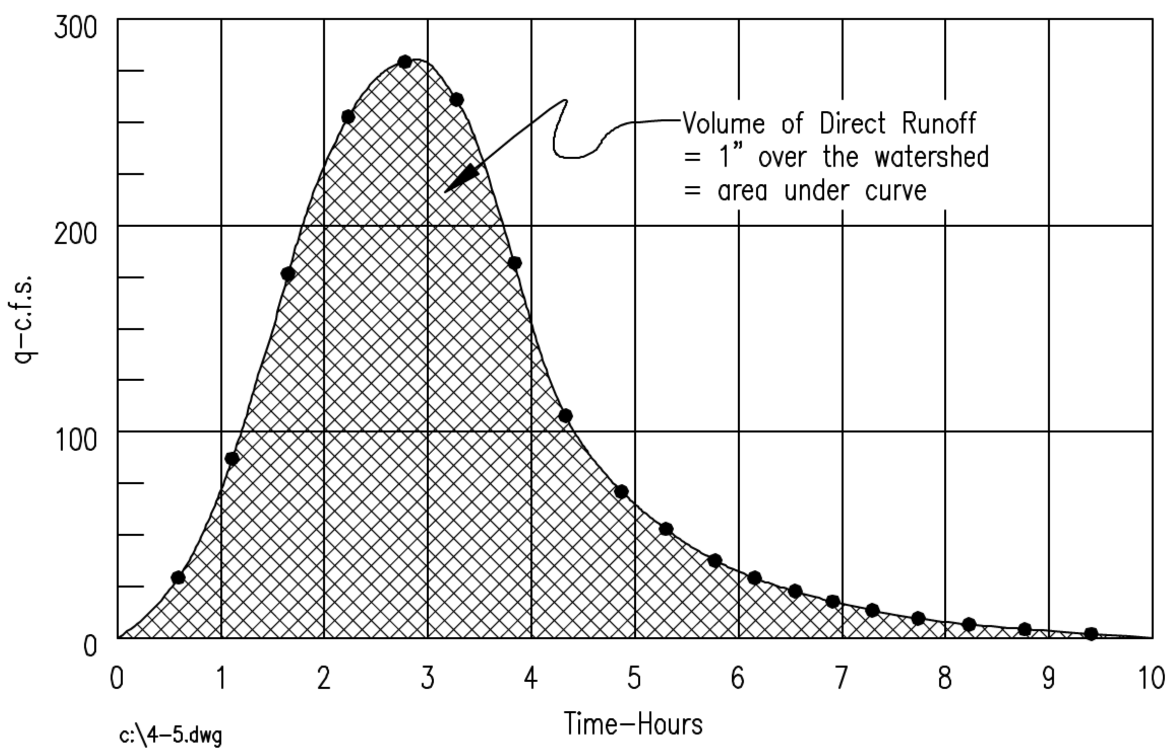
A ***synthetic hydrograph*** is a hydrograph which is generated from the synthesis of data from a large number of watersheds. The basis of a synthetic hydrograph is the establishment of a relationship between the physical geometry of the watersheds and resulting hydrographs. The most commonly used synthetic hydrograph for modeling and design is the ***unit hydrograph***. The following section briefly describes synthetic unit hydrograph methods.

4-3.3 Synthetic Unit Hydrographs

The ***unit hydrograph*** is the hydrograph that results from 1 inch of precipitation excess generated uniformly over the watershed at a uniform rate during a specified time period.

The shape and characteristics of the runoff hydrograph for a given watershed are determined by the specific characteristics of the storm and the physical characteristics of the watershed. Since the physical characteristics of a watershed (shape, slope, ground cover, etc.) are constant, one might expect considerable similarity in the shape of hydrographs from storms of similar rainfall characteristics. This is the essence of the unit hydrograph. The unit hydrograph is a typical hydrograph for a watershed where the runoff volume under the hydrograph is adjusted to equal 1 inch of equivalent depth over the watershed, as shown in **Figure 4-5.**

FIGURE 4 - 5
Typical Synthetic Unit Hydrograph



As mentioned, the unit hydrograph shape is also determined by the storm characteristics, such as rainfall duration, time-intensity patterns, area distribution of rainfall, and depth of rainfall. The following assumptions are made regarding the rainfall-runoff relationship when using a unit hydrograph:

1. *The runoff is from precipitation excess, the difference between precipitation and losses.*

2. *The volume of runoff is* ***1 inch****, which is equal to the precipitation excess.*

3. *The precipitation excess is applied at a constant/uniform rate.*

4. *The excess is applied with uniform spatial distribution.*

5. *The intensity of rainfall excess is constant over the duration.*

Many of these same assumptions are made when using almost any single-event hydrologic model. These assumptions, however, do not hold true for all storms. Therefore, one can expect variations in the ordinates of the unit hydrograph for different storms.

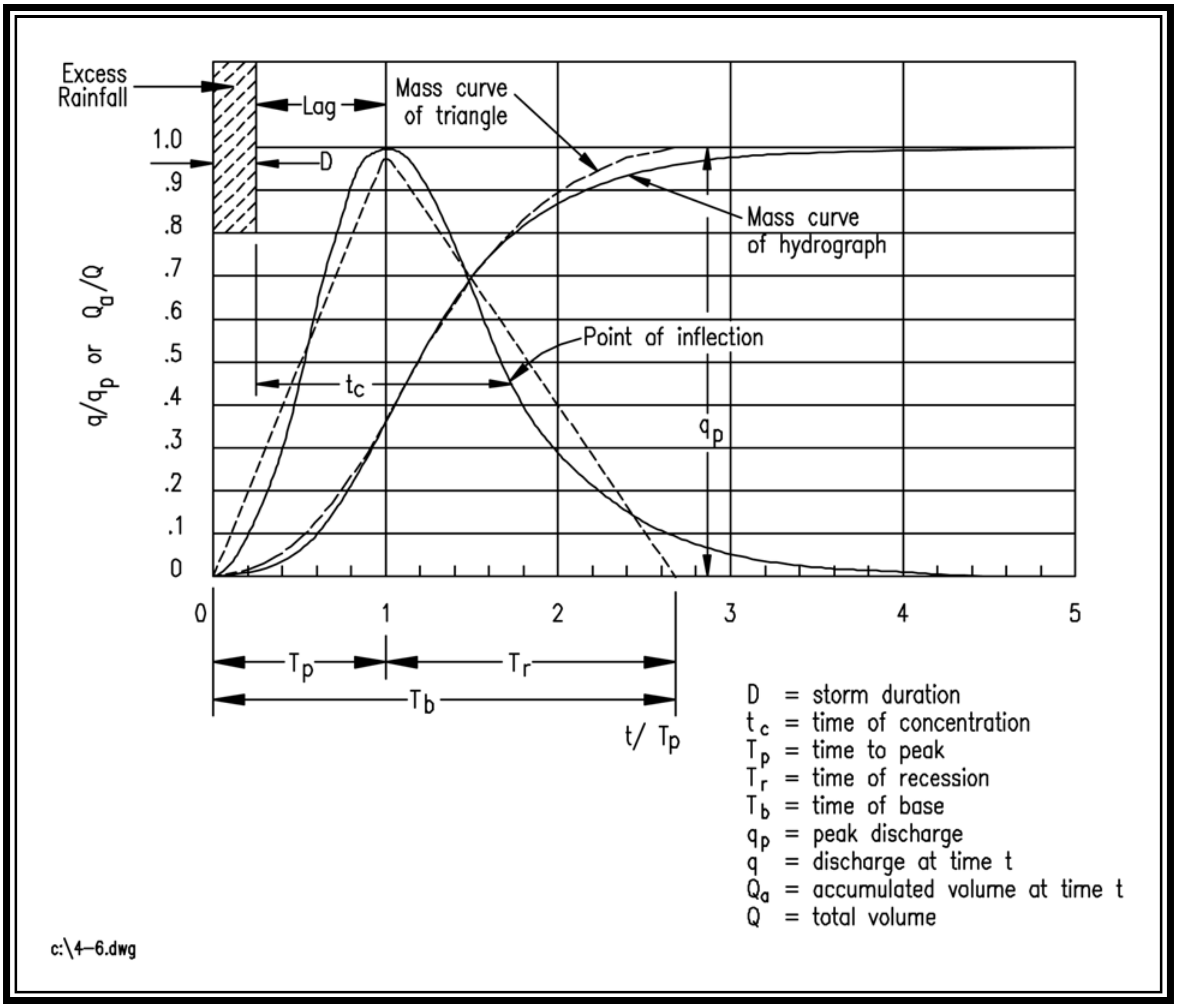
The unit hydrograph does not represent either the total runoff volume or the design hydrograph. The unit hydrograph is simply used to translate the time distribution of precipitation excess into a runoff hydrograph. In other words, the unit hydrograph provides the shape for the actual runoff hydrograph. The physical characteristics of the watershed and the amount of precipitation excess, as determined by the storm event and the rainfall-runoff relationship, will translate the unit hydrograph into the actual runoff hydrograph. The peak discharge and the time to peak are considered to be the defining parameters of the physical characteristics of the watershed. The unit hydrograph is translated into an actual runoff hydrograph through a process called convolution, which takes into account the ***peak*** and ***time to peak***. The convolution process is an exercise in multiplication, translation with time, and addition.

A unit hydrograph can be based on the analysis of a single watershed and can be used specifically for that watershed. This is often the case when conducting flood studies for river basins. Rainfall-runoff and streamflow data compiled within the watershed are analyzed and a unit hydrograph is generated to better predict the response characteristics to various storm events. Generally, however, basic streamflow and runoff data are not available to create a unit hydrograph for most development projects. Therefore, techniques have been developed that allow for the generation of synthetic unit hydrographs.

4-3.4 SCS Dimensionless Unit Hydrograph

The method developed by the Soil Conservation Service (SCS) for constructing synthetic unit hydrographs is based on the ***dimensionless unit hydrograph***. This dimensionless graph is the result of an analysis of a large number of natural unit hydrographs from a wide range of watersheds varying in size and geographic locations. This approach is based on using the watershed peak discharge and time to peak discharge to relate the watershed characteristics to the dimensionless hydrograph features. SCS methodologies provide various empirical equations, as discussed in this chapter, to solve for the ***peak*** and ***time to peak*** for a given watershed. Various equations are then used to define critical points on the hydrograph and thus define the runoff hydrograph. **Figure 4-6** shows the SCS Dimensionless Unit Hydrograph. The critical points are the ***time to peak***, represented by the watershed ***lag time***, and the ***point of inflection***, represented by the ***time of concentration***. The *lag time* of a watershed is the time from the center of mass of excess rainfall to the time to peak of a unit hydrograph. The average relationship of lag, L, to time of concentration, t_c, is $L = 0.6\ t_c$. The reader is encouraged to read Chapters 15 and 16 of the National Engineering Handbook, Section 4; Hydrology, for more information on unit hydrographs.

FIGURE 4 - 6
Dimensionless Curvilinear Unit Hydrograph and Equivalent Triangular Hydrograph



Source: NEH-4, Chapter 16

4-4 RUNOFF and PEAK DISCHARGE

The practice of estimating runoff as a fixed percentage of rainfall has been used in the design of storm drainage systems for over 100 years. Despite its simplification of the complex rainfall - runoff processes, it is still the most commonly used method for urban drainage calculations. It can be accurate when drainage areas are subdivided into homogenious units, and when the designer has enough data and experience to use the appropriate factors..

For watersheds or drainage areas comprised primarily of pervious cover such as open space, woods, lawns, or agricultural land uses, the rainfall/runoff analysis becomes much more complex. Soil conditions and types of vegetation are two of the variables that play a larger role in determining the amount of rainfall which becomes runoff. In addition, other types of flow have a larger effect on stream flow (and measured hydrograph) when the watershed is less urbanized. These are:

1. **Surface runoff** occurs only when the rainfall rate is greater than the infiltration rate and the total volume of rainfall exceeds the interception, infiltration, and surface detention capacity of the watershed. The runoff flows on the land surface collecting in the stream network.

2. **Subsurface flow** occurs when infiltrated rainfall meets an underground zone of low transmission and travels above the zone to the soil surface to appear as a seep or spring.

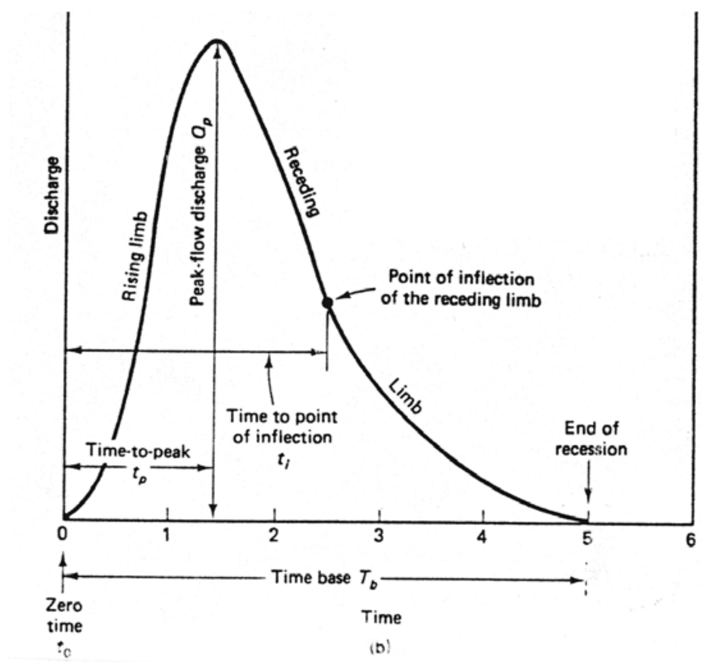
3. **Base flow** occurs when there is a fairly steady flow into a stream channel from natural storage. The flow comes from lakes or swamps, or from an aquifer replenished by infiltrated rainfall or surface runoff.

In watershed hydrology, it is customary to deal separately with base flow and to combine all other types of flow into direct runoff. Depending upon the requirements of the study, the designer can calculate the ***peak flow rate***, in *cfs* (cubic feet per second), of the direct runoff from the watershed, or determine the ***runoff hydrograph*** for the direct runoff from the watershed. A ***hydrograph*** is a plot of *discharge* or *runoff*, on the vertical axis, versus *time*, on the horizontal axis, as shown in **Figure 4-7**. A hydrograph shows the volume of runoff as the area beneath the curve, and the time-variation of the discharge rate.

If the purpose of a hydrologic study is to measure the impact of various developments on the drainage network within a watershed or to design flood control structures, then a hydrograph is needed. If the purpose of a study is to design a roadway culvert or other simple drainage improvement, then only the peak rate of flow is needed. Therefore, the purpose of a given study will dictate the methodology which should be used. **Procedures such as the Rational Method and TR-55 Graphical Peak Discharge Method *do not* generate a runoff hydrograph. The TR-55 Tabular Method and the Modified Rational Method *do* generate runoff hydrographs**.

This section will present some of the different methods for calculating runoff from a watershed. Designers should be familiar with all of them since they require different types of input and generate different types of results.

FIGURE 4 - 7
Runoff Hydrograph



The methods covered here are: The Rational Method, Modified Rational Method, and SCS Methods' TR-55, Urban Hydrology for Small Watersheds (USDA 1986): Graphical Peak Discharge and Tabular Hydrograph Methods. Many computer programs are available which develop these methodologies, utilizing the rainfall-runoff relationship described previously. Many of these programs also "route" the runoff hydrograph through a stormwater management facility, calculating the peak rate of discharge and a discharge hydrograph.

Examples provided in Chapter 6 utilize SCS TR-20 "Project Formulation, Hydrology (USDA 1982). Other readily available computer programs also utilize SCS Methods. Additional examples utilizing many different computer programs which offer a variety of hydrologic methods will be provided through DCR as ongoing guidance. The accuracy of the computer model is based upon the accuracy of the input which is typically generated through the Rational or SCS methodologies covered here. The designer should be familiar with all of the methods covered here since any one may be appropriate for the specific site on watershed being modeled.

All the methods presented here make assumptions and have limitations on the accuracy. Simply put, however, when these methods are used correctly, they will all provide a reasonable estimate of the peak rate of runoff from a drainage area or watershed.

It should be noted that for small storm events (< 2" rainfall) TR-55 tends to underestimate the runoff, while it has been shown to be fairly accurate for larger storm events (Pitt, 1994). Similarly, the Rational formula has been found to be fairly accurate on smaller homogeneous watersheds, while tending to lose accuracy in the larger more complex watersheds. The following discussion provides further explanation of these methods, including assumptions, limitations, and information needed for the analysis.

4-4.1 The Rational Method

The Rational Method was introduced in 1880 for determining peak discharges from drainage areas. It is frequently criticized for its simplistic approach, but this same simplicity has made the Rational Method one of the most widely used techniques today.

The Rational Formula estimates the peak rate of runoff at any location in a drainage area as a function of the *runoff coefficient*, *mean rainfall intensity*, and *drainage area*. The ***Rational Formula*** is expressed as follows:

$$Q = C\,I\,A$$

Equation 4-1
Rational Formula

where: Q = *maximum rate of runoff, cfs*
C = *dimensionless runoff coefficient, dependent upon land use*
I = *design rainfall intensity, in inches per hour, for a duration equal to the time of concentration of the watershed*
A = *drainage area, in acres*

4-4.1.1 Assumptions

The Rational Method is based on the following assumptions:

1) *Under steady rainfall intensity, the maximum discharge will occur at the watershed outlet at the time when the entire area above the outlet is contributing runoff.*

This "time" is commonly known as the ***time of concentration***, t_c, and is defined as the time required for runoff to travel from the most hydrologically distant point in the watershed to the outlet.

The assumption of steady rainfall dictates that even during longer events, when factors such as increasing soil saturation are ignored, the ***maximum discharge*** occurs when the entire watershed is contributing to the peak flow, at time $t = t_c$.

Furthermore, this assumption limits the size of the drainage area that can be analyzed using the rational method. In large watersheds, the time of concentration may be so long that constant rainfall intensities may not occur for long periods. Also, shorter, more intense bursts of rainfall that occur over portions of the watershed may produce large peak flows.

2) *The time of concentration is equal to the minimum duration of peak rainfall.*

The time of concentration reflects the minimum time required for the entire watershed to contribute to the peak discharge as stated above. The rational method assumes that the discharge does not increase as a result of soil saturation, decreased conveyance time, etc. (refer to **Figure 4-8**). Therefore, the time of concentration is not necessarily intended to be a measure of the actual storm duration, but simply the critical time period used to determine the average rainfall intensity from the Intensity-Duration-Frequency curves.

3) *The frequency or return period of the computed peak discharge is the same as the frequency or return period of rainfall intensity (design storm) for the given time of concentration.*

Frequencies of peak discharges depend not only on the frequency of rainfall intensity, but also the response characteristics of the watershed. For small and mostly impervious areas, rainfall frequency is the dominant factor since response characteristics are relatively constant. However, for larger watersheds, the response characteristics will have a much greater impact on the frequency of the peak discharge due to drainage structures, restrictions within the watershed, and initial rainfall losses from interception and depression storage.

4) The fraction of rainfall that becomes runoff is independent of rainfall intensity or volume.

This assumption is reasonable for impervious areas, such as streets, rooftops, and parking lots. For pervious areas, the fraction of rainfall that becomes runoff varies with rainfall intensity and the accumulated volume of rainfall. As the soil becomes saturated, the fraction of rainfall that becomes runoff will increase. This fraction is represented by the dimensionless runoff coefficient, C. Therefore, the accuracy of the rational method is dependent on the careful selection of a coefficient that is appropriate for the storm, soil, and land use conditions. Selection of appropriate C values will be discussed later in this chapter.

It is easy to see why the rational method becomes more accurate as the percentage of impervious cover in the drainage area approaches 100 percent.

5) *The peak rate of runoff is sufficient information for the design of stormwater detention and retention facilities.*

4-4.1.2 Limitations

Because of the assumptions discussed above, the rational method should only be used when the following criteria are met:

1) *The given watershed has a time of concentration, t_c , less than 20 minutes;*

2) *The drainage area is less than 20 acres.*

For larger watersheds, attenuation of peak flows through the drainage network begins to be a factor in determining peak discharge. While there are ways to adjust runoff coefficients (CN factors) to account for the attenuation, or routing effects, it is better to use a hydrograph method or computer simulation for these more complex situations.

Similarly, the presence of bridges, culverts, or storm sewers may act as restrictions which ultimately impact the peak rate of discharge from the watershed. The peak discharge upstream of the restriction can be calculated using a simple calculation procedure, such as the Rational Method, however a detailed storage routing procedure which considers the storage volume above the restriction should be used to accurately determine the discharge downstream of the restriction.

4-4.1.3 Design Parameters

The following is a brief summary of the design parameters used in the rational method:

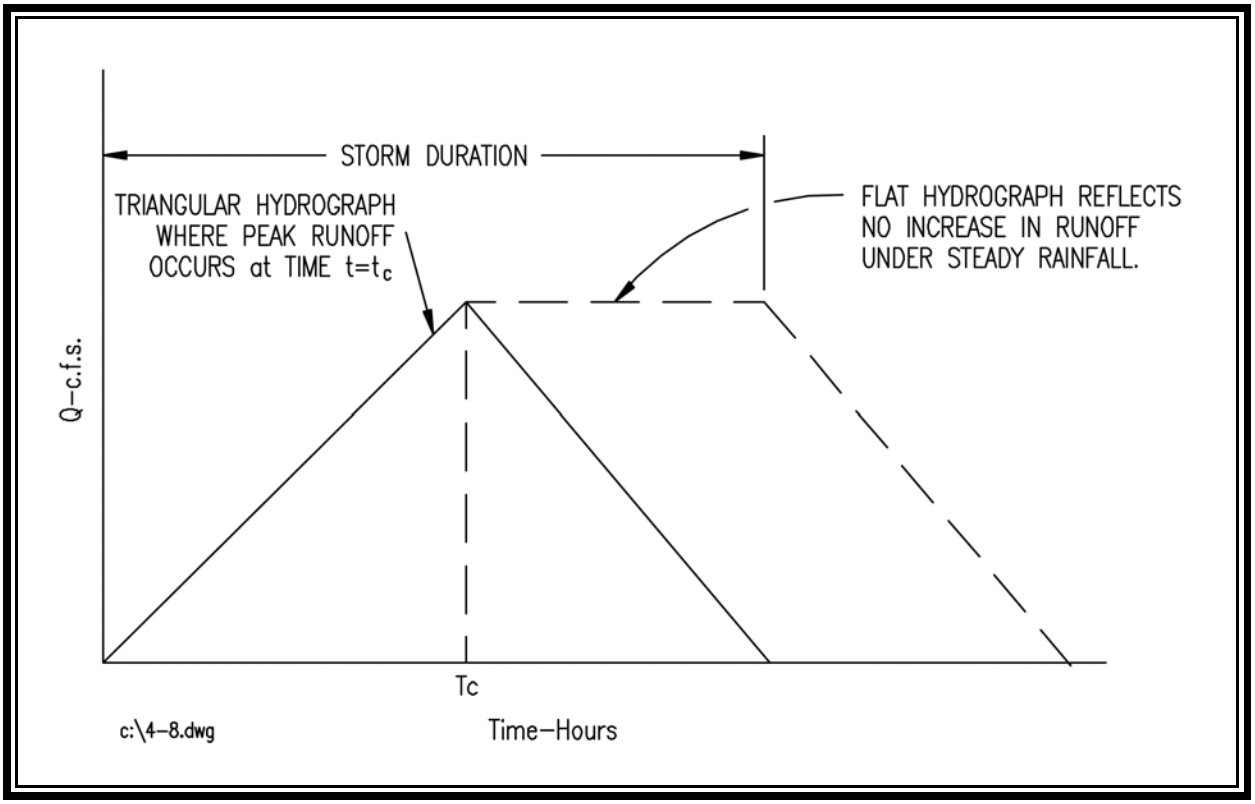
1) Time of concentration, t_c

The most consistent source of error in the use of the rational method is the oversimplification of the time of concentration calculation procedure. Since the origin of the rational method is rooted in the design of culverts and conveyance systems, the main components of the time of concentration are *inlet time* (or overland flow) and *pipe or channel flow time*. The *inlet or overland flow time* is defined as the time required for runoff to flow overland from the furthest point in the drainage area over the surface to the inlet or culvert. The *pipe or channel flow time* is defined as the time required for the runoff to flow through the conveyance system to the design point. In addition, when an inlet time of less than 5 minutes is encountered, the time is rounded up to 5 minutes, which is then used to determine the rainfall intensity, *I*, for that inlet.

Variations in the time of concentration can impact the calculated peak discharge. When the procedure for calculating the time of concentration is oversimplified, as mentioned above, the accuracy of the Rational Method is greatly compromised. To prevent this oversimplification, it is recommended that a more rigorous procedure for determining the time of concentration be used, such as those outlined in **Section 4-4.3.2** of this manual, Chapter 5 of the Virginia Erosion and Sediment Control Handbook (VESCH), 1992 edition, Chapter 15, Section 4 of SCS National Engineering Handbook, or the Virginia Department of Transportation (VDOT) drainage manual.

There are many procedures for estimating the time of concentration. Some were developed with a specific type or size watershed in mind, while others were based on studies of a specific watershed. The selection of any given procedure should include a comparison of the hydrologic and hydraulic characteristics used in the formation of the procedure, versus the characteristics of the watershed

FIGURE 4 - 8
Rational Method Runoff Hydrograph



under study. The designer should be aware that if two or more methods of determining time of concentration are applied to a given watershed, there will likely be a wide range in results. The SCS method is recommended because it provides a means of estimating overland sheet flow time and shallow concentrated flow time as a function of readily available parameters such as land slope and land surface conditions. Regardless of which method is used, the result should be reasonable when compared to an average flow time over the total length of the watershed.

2) Rainfall Intensity, I

The rainfall intensity, *I*, is the average rainfall rate, in inches per hour, for a storm duration equal to the time of concentration for a selected return period (i.e., 1-year, 2-year, 10-year, 25-year, etc.). Once a particular return period has been selected, and the time of concentration has been determined for the drainage area, the rainfall intensity can be read from the appropriate rainfall Intensity-

Duration-Frequency (I-D-F) curve for the geographic area in which the drainage area is located. These charts were developed from data furnished by the National Weather Service for regions of Virginia, and are provided in the Appendix at the end of this chapter.

3) Runoff Coefficient, C

The runoff coefficients for different land uses within a watershed are used to generate a single, weighted coefficient that will represent the relationship between rainfall and runoff for that watershed. Recommended values can be found in **Table 4-3**. In an attempt to make the rational method more accurate, efforts have been made to adjust the runoff coefficients to represent the integrated effects of drainage basin parameters: *land use*, *soil type*, and *average land slope*. **Table 4-3** provides recommended coefficients based on urban land use only, while **Table 4-5** gives recommended coefficients for various land uses based on soil type and land slope parameters.

A good understanding of these parameters is essential in choosing an appropriate coefficient. As the slope of a drainage basin increases, runoff velocities increase for both sheet flow and shallow concentrated flow. As the velocity of runoff increases, the ability of the surface soil to absorb the runoff decreases. This decrease in infiltration results in an increase in runoff. In this case, the designer should select a higher runoff coefficient to reflect the increase due to slope.

Soil properties influence the relationship between runoff and rainfall even further since soils have differing rates of infiltration. Historically, the Rational Method was used primarily for the design of storm sewers and culverts in urbanizing areas; soil characteristics were not considered, especially when the watershed was largely impervious. In such cases, a conservative design simply meant a larger pipe and less headwater. For stormwater management purposes, however, the existing condition (prior to development, usually with large amounts of pervious surfaces) often dictates the allowable post-development release rate, and therefore, must be accurately modeled.

Soil properties can change throughout the construction process due to compaction, cut, and fill operations. If these changes are not reflected in the runoff coefficient, the accuracy of the model will decrease. Some localities arbitrarily require an adjustment in the runoff coefficient for pervious surfaces due to the effects of construction on soil infiltration capacities. This is discussed in more detail in **Section 4-4.3** of this handbook. Such an adjustment is not possible using the Rational Method since soil conditions are not considered. However, **Table 4-5** attempts to provide a graduated scale which correlates the rational method runoff coefficient with soil and land condition characteristics.

4) Adjustment for Infrequent Storms

The Rational Method has undergone further adjustment to account for infrequent, higher intensity storms. This adjustment is in the form of a frequency factor, C_f, which accounts for the reduced impact of infiltration and other effects on the amount of runoff during larger storms. With the adjustment, the Rational Formula is expressed as follows:

$$Q = C\,C_f\,I\,A$$

Equation 4-2
Rational Formula Frequency Factor

The C_f values are listed in **Table 4-4**. The product of $C_f \times C$ should not exceed 1.0.

TABLE 4 - 3
Rational Equation Runoff Coefficients

Land use	"*C*" Value
Business, industrial and commercial	0.90
Apartments	0.75
Schools	0.60
Residential - lots of 10,000 *sq. ft.*	0.50
- lots of 12,000 *sq. ft.*	0.45
- lots of 17,000 *sq. ft.*	0.45
- lots of ½ acre or more	0.40
Parks, cemeteries and unimproved areas	0.34
Paved and roof areas	0.90
Cultivated areas	0.60
Pasture	0.45
Forest	0.30
Steep grass slopes (2:1)	0.70
Shoulder and ditch areas	0.50
Lawns	0.20

Source:VDOT

TABLE 4 - 4
Rational Equation Frequency Factors

C_f	Storm Return Frequency
1.0	10 *yr.* or less
1.1	25 *yr.*
1.2	50 *yr.*
1.25	100 *yr.*

Source: VDOT

TABLE 4 - 5a
Rational Equation Coefficients for SCS Hydrologic Soil Groups (A, B, C, D)
Urban Land Uses

STORM FREQUENCIES OF LESS THAN 25 YEARS													
Land Use	Hydrologic Condition	HYDROLOGIC SOIL GROUP/SLOPE											
		A			B			C			D		
		0-2%	2-6%	6%+	0-2%	2-6%	6%+	0-2%	2-6%	6%+	0-2%	2-6%	6%+
Paved Areas and Impervious Surfaces		0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Open Space, Lawns, etc.	Good	0.08	0.12	0.15	0.11	0.16	0.21	0.14	0.19	0.24	0.20	0.24	0.28
Industrial		0.67	0.68	0.68	0.68	0.68	0.69	0.68	0.69	0.69	0.69	0.69	0.70
Commercial		0.71	0.71	0.72	0.71	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
Residential Lot Size 1/8 Acre		0.25	0.28	0.31	0.27	0.30	0.35	0.30	0.33	0.38	0.33	0.36	0.42
Lot Size 1/4 Acre		0.22	0.26	0.29	0.24	0.29	0.33	0.27	0.31	0.36	0.30	0.34	0.40
Lot Size 1/3 Acre		0.19	0.23	0.26	0.22	0.26	0.30	0.25	0.29	0.34	0.28	0.32	0.39
Lot Size ½ Acre		0.16	0.20	0.24	0.19	0.23	0.28	0.22	0.27	0.32	0.26	0.30	0.37
Lot Size 1.0 Acre		0.14	0.19	0.22	0.17	0.21	0.26	0.20	0.25	0.31	0.24	0.29	0.35

Source: Maryland State Highway Administration

TABLE 4 - 5b

Rational Equation Coefficients for SCS Hydrologic Soil Groups (A, B, C, D)

Rural Land Uses

STORM FREQUENCIES OF LESS THAN 25 YEARS														
Land Use	Treatment / Practice	Hydrologic Condition	HYDROLOGIC SOIL GROUP/SLOPE											
			A			B			C			D		
			0-2%	2-6%	6%+	0-2%	2-6%	6%+	0-2%	2-6%	6%+	0-2%	2-6%	6%+
Pasture or Range		Good	0.07	0.09	0.10	0.18	0.20	0.22	0.27	0.29	0.31	0.32	0.34	0.35
	Contoured	Good	0.03	0.04	0.06	0.11	0.12	0.14	0.24	0.26	0.28	0.31	0.33	0.34
Meadow			0.06	0.08	0.10	0.10	0.14	0.19	0.12	0.17	0.22	0.15	0.20	0.25
Wooded		Good	0.05	0.07	0.08	0.08	0.11	0.15	0.10	0.13	0.17	0.12	0.15	0.21

Source: Maryland State Highway Administration

TABLE 4 - 5c
Rational Equation Coefficients for SCS Hydrologic Soil Groups (A, B, C, D)
Agricultural Land Uses

STORM FREQUENCIES OF LESS THAN 25 YEARS														
Land Use	Treatment/ Practice	Hydrologic Condition	HYDROLOGIC SOIL GROUP/SLOPE											
			A			B			C			D		
			0-2%	2-6%	6%+	0-2%	2-6%	6%+	0-2%	2-6%	6%+	0-2%	2-6%	6%+
Fallow	Straight Row		0.41	0.48	0.53	0.60	0.66	0.71	0.72	0.78	0.82	0.84	0.88	0.91
Row Crops	Straight Row	Good	0.24	0.30	0.35	0.43	0.48	0.52	0.61	0.65	0.68	0.73	0.76	0.78
	Contoured	Good	0.21	0.26	0.30	0.41	0.45	0.49	0.55	0.59	0.63	0.63	0.66	0.68
	Contoured and Terraced	Good	0.20	0.24	0.27	0.31	0.35	0.39	0.45	0.48	0.51	0.55	0.58	0.60
Small Grain	Straight Row	Good	0.23	0.26	0.29	0.42	0.45	0.48	0.57	0.60	0.62	0.71	0.73	0.75

Source: Maryland State Highway Administration

TABLE 4 - 5d

Rational Equation Coefficients for SCS Hydrologic Soil Groups (A, B, C, D)

Agricultural Land Uses

STORM FREQUENCIES OF LESS THAN 25 YEARS														
Land Use	Treatment/ Practice	Hydrologic Condition	HYDROLOGIC SOIL GROUP/SLOPE											
			A			B			C			D		
			0-2%	2-6%	6%+	0-2%	2-6%	6%+	0-2%	2-6%	6%+	0-2%	2-6%	6%+
Small Grain	Contoured	Good	0.17	0.22	0.27	0.33	0.38	0.42	0.54	0.58	0.61	0.62	0.65	0.67
	Contoured and Terraced	Good	0.16	0.20	0.24	0.31	0.35	0.38	0.45	0.48	0.50	0.55	0.58	0.60
Closed-seeded Legumes or Rotation Meadow	Straight Row	Good	0.15	0.19	0.23	0.31	0.35	0.38	0.55	0.58	0.60	0.63	0.65	0.66
	Contoured	Good	0.14	0.18	0.21	0.30	0.34	0.37	0.45	0.48	0.51	0.58	0.60	0.61
	Contoured and Terraced	Good	0.07	0.10	0.13	0.28	0.32	0.35	0.44	0.47	0.49	0.52	0.54	0.56

Source: Maryland State Highway Administration

4-4.2 Modified Rational Method

The modified rational method is a variation of the rational method, developed mainly for the sizing of detention facilities in urban areas. The modified rational method is applied similarly to the rational method except that it utilizes a fixed rainfall duration. The selected rainfall duration depends on the requirements of the user. For example, the designer might perform an iterative calculation to determine the rainfall duration which produces the maximum storage volume requirement when sizing a detention basin. This procedure will be discussed later in **Chapter 5**, **Hydraulic Calculations**.

4-4.2.1 Assumptions

The modified rational method is based on the following assumptions:

1. *All of the assumptions used with the rational method apply. The most significant difference is that the time of concentration for the modified rational method is equal to the rainfall intensity averaging period rather than the actual storm duration.*

This assumption means that any rainfall, or any runoff generated by the rainfall, that occurs before or after the ***rainfall averaging period*** is unaccounted for. **Thus, when used as a basin sizing procedure, the modified rational method may seriously underestimate the required storage volume**. (Walesh, 1989)

2) *The runoff hydrograph for a watershed can be approximated as triangular or trapezoidal in shape*.

This assumption implies a linear relationship between ***peak discharge*** and ***time*** for any and all watersheds.

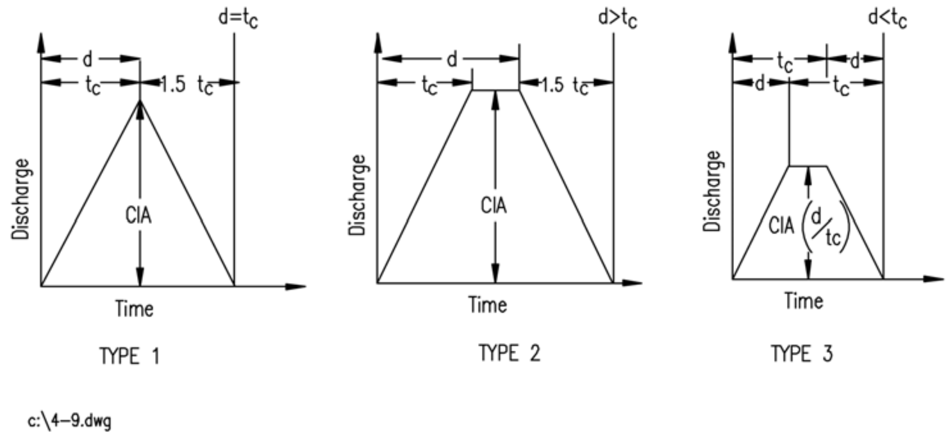
4-4.2.2 Limitations

All of the limitations listed for the rational method apply to the modified rational method. The key difference is the assumed shape of the resulting runoff hydrograph. The rational method produces a triangular shaped hydrograph, while the modified rational method can generate triangular or trapezoidal hydrographs for a given watershed, as shown in **Figure 4-9**.

4-4.2.3 Design Parameters

The equation $Q = C\,I\,A$ (the rational equation) is used to calculate the peak discharge for all three hydrographs shown in **Figure 4-9**. Notice that the only difference between the rational method and the modified rational method is the incorporation of the *storm duration*, d, into the modified rational method to generate a *volume* of runoff in addition to the peak discharge.

FIGURE 4 - 9
Modified Rational Method Runoff Hydrographs



Type 1 - Storm duration, *d*, is equal to the time of concentration, t_c.
Type 2 - Storm duration, *d*, is greater than the time of concentration, t_c.
Type 3 - Storm duration, *d*, is less than the time of concentration, t_c.

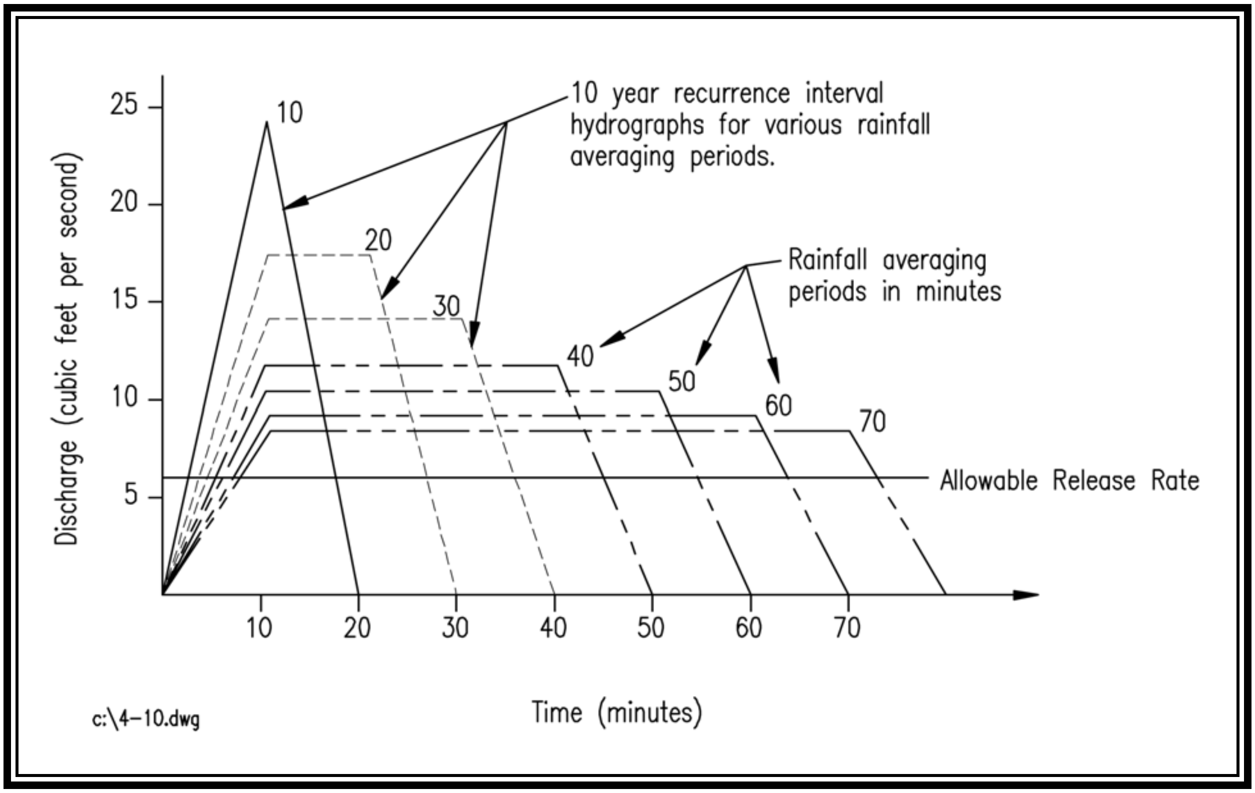
Source: Urban Surface Water Management, Walesh, Stuart G.

The rational method generates the peak discharge that occurs when the entire watershed is contributing to the peak (at a time $t = t_c$) and ignores the effects of a storm which lasts longer than time t. The modified rational method, however, considers storms with a longer duration than the watershed t_c, which may have a smaller or larger peak rate of discharge, but will produce a greater volume of runoff (area under the hydrograph) associated with the longer duration of rainfall. **Figure 4-10** shows a family of hydrographs representing storms of different durations. The storm duration which generates the greatest volume of runoff may not necessarily produce the greatest peak rate of discharge.

Note that the duration of the receding limb of the hydrograph is set to equal the time of concentration, t_c, or 1.5 times t_c. The direct solution, which will be discussed in **Chapter 5**, uses $1.5t_c$ as the receding limb. This is justified since it is more representative of actual storm and runoff dynamics. (It is also more similar to the SCS unit hydrograph where the receding limb extends longer than the rising limb.) **Using 1.5 times t_c in the direct solution methodology provides for a more conservative design and will be used in this manual**.

The modified rational method allows the designer to analyze several different storm durations to determine the one that requires the greatest storage volume with respect to the allowable release rate. This storm duration is referred to as the ***critical storm duration*** and is used as a basin sizing tool. The technique is discussed in more detail in **Chapter 5** of this handbook.

FIGURE 4 - 10
Modified Rational Method Family of Runoff Hydrographs



4-4.3 SCS Methods - TR-55 Estimating Runoff

The U.S. Soil Conservation Service published Technical Release Number 55 (TR-55), 2nd edition, in June of 1986, entitled Urban Hydrology for Small Watersheds. The techniques outlined in TR-55 require the same basic data as the rational method: drainage area, time of concentration, land use and rainfall. The SCS approach, however, is more sophisticated in that it allows the designer to manipulate the time distribution of the rainfall, the initial rainfall losses to interception and depression storage, and the moisture condition of the soils prior to the storm.

The procedures developed by SCS are based on a dimensionless rainfall distribution curve for a 24-hour storm, as described in **Section 4-2.3**.

TR-55 presents two general methods for estimating peak discharges from urban watersheds: the ***graphical method*** and the ***tabular method***. The ***graphical method*** is limited to watersheds whose runoff characteristics are fairly uniform and whose soils, land use, and ground cover can be represented by a single Runoff Curve Number (*CN*). The graphical method provides a peak discharge only and is not applicable for situations where a hydrograph is required.

The ***tabular method*** is a more complete approach and can be used to develop a hydrograph at any point in a watershed. For large areas it may be necessary to divide the area into sub-watersheds to account for major land use changes, analyze specific study points within sub-watersheds, or locate stormwater drainage facilities and assess their effects on peak flows. The tabular method can generate a hydrograph for each sub-watershed for the same storm event. The hydrographs can then be ***routed*** through the watershed and combined to produce a partial composite hydrograph at the selected study point. The tabular method is particularly useful in evaluating the effects of an altered land use in a specific area within a given watershed.

Prior to using either the graphical or tabular methods, the designer must determine the volume of runoff resulting from a given depth of precipitation and the time of concentration, t_c , for the watershed being analyzed. The methods for determining these values will be discussed briefly in this section. However, the reader is strongly encouraged to obtain a copy of the TR-55 manual from the Soil Conservation Service to gain more insight into the procedures and limitations.

The SCS ***Runoff Curve Number (CN) Method*** is used to estimate runoff. This method is described in detail in the SCS National Engineering Handbook, Section 4 (SCS 1985). The runoff equation (found in TR-55 and discussed later in this section) provides a relationship between runoff and rainfall as a function of the *CN*. The *CN* is a measure of the land's ability to infiltrate or otherwise detain rainfall, with the excess becoming runoff. The *CN* is a function of the land cover (woods, pasture, agricultural use, percent impervious, etc.), hydrologic condition, and soils.

4-4.3.1 Limitations

1. *TR-55 has simplified the relationship between rainfall and runoff by reducing all of the initial losses before runoff begins, or initial abstraction, to the term I_a, and approximating the soil and cover conditions using the variable S, potential maximum retention. Both of these terms, I_a and S, are functions of the runoff curve number.*

Runoff curve numbers describe average conditions that are useful for design purposes. If the purpose of the hydrologic study is to model a historical storm event, average conditions may not be appropriate.

2. *The designer should understand the assumption reflected in the initial abstraction term, I_a. I_a represents interception, initial infiltration, surface depression storage, evapotranspiration, and other watershed factors and is generalized as a function of the runoff curve number based on data from agricultural watersheds.*

This can be especially important in an urban application because the combination of impervious area with pervious area can imply a significant initial loss that may not take place. On the other hand, the combination of impervious and pervious area can underestimate initial losses if the urban area has significant surface depression storage. (To use a relationship other than the one established in TR-55, the designer must redevelop the runoff equation by using the original rainfall-runoff data to establish new curve number relationships for each cover and hydrologic soil group. This would represent a large data collection and analysis effort.)

3. *Runoff from snowmelt or frozen ground cannot be estimated using these procedures.*

4. *The runoff curve number method is less accurate when the runoff is less than 0.5 inch. As a check, use another procedure to determine runoff.*

5. *The SCS runoff procedures apply only to surface runoff and do not consider subsurface flow or high groundwater.*

6. *Manning's kinematic solution (**Chapter 4-4.3.3.E**) should not be used to calculate the time of concentration for sheet flow longer than 300 feet. This limitation will affect the time of concentration calculations. Note that many jurisdictions consider 150 feet to be the maximum length of sheet flow before shallow concentrated flow develops*.

7. *The minimum t_c used in TR-55 is 0.1 hour.*

4-4.3.2 Information Needed

Generally a good understanding of the physical characteristics of the watershed is needed to solve the runoff equation and determine the time of concentration. Some features, such as topography and channel geometry can be obtained from topographic maps such as the USGS *1″ = 2000′* quadrangle maps. Various sources of information may be accurate enough for a watershed study, however, the accuracy of the study will be directly related to the accuracy and level of detail of the base information. Ideally, a site investigation and field survey should be conducted to verify specific features such as channel geometry and material, culvert sizes, drainage divides, ground cover, etc. Depending on the size and scope of the study, however, a site investigation may not be economically feasible.

The data needed to solve the runoff equation and determine the watershed time of concentration, t_c , and travel time, T_t , is listed below. These items are discussed in more detail in **Section 4-4.3.3**.

1. *Soil information (to determine the hydrologic soil group).*

2. *Ground cover type (impervious, woods, grass, etc.).*

3. *Treatment (cultivated or agricultural land).*

4. *Hydrologic condition (for design purposes, the hydrologic condition should be considered "GOOD" for the pre-developed condition).*

5. *Urban impervious area modifications (connected, unconnected, etc.).*

6. *Topography – detailed enough to accurately identify drainage divides, t_c and T_t flow paths and channel geometry, and surface condition (roughness coefficient).*

4-4.3.3 Design Parameters

A. Soils

In hydrograph applications, runoff is often referred to as ***rainfall excess*** or ***effective rainfall***, and is defined as the amount of rainfall that exceeds the land's capability to infiltrate or otherwise retain the rainwater. The soil type or classification, the land use and land treatment, and the hydrologic condition of the cover are the watershed factors that will have the most significant impact on estimating the volume of rainfall excess, or runoff.

HYDROLOGIC SOIL GROUP CLASSIFICATION

SCS has developed a soil classification system that consists of four groups, identified as ***A***, ***B***, ***C***, and ***D***. Soils are classified into one of these categories based upon their ***minimum infiltration rate***. By using information obtained from local SCS offices, soil and water conservation district offices, or from SCS Soil Surveys (published for many counties across the country), the soils in a given area can be identified. Preliminary soil identification is especially useful for watershed analysis and planning in general. When preparing a stormwater management plan for a specific site, it is recommended that soil borings be taken to verify the hydrologic soil classification. Virginia soils and their respective ***Hydrologic Soil Group*** (***HSG***) classifications are provided in the Appendix at the end of this Chapter, as well as VESCH, 1992 edition. TR-55 contains similar information for soils across the United States.

Soil characteristics associated with each Hydrologic Soil Group are generally described as follows:

Group A: Soils with low runoff potential due to high infiltration rates, even when thoroughly wetted. These soils consist primarily of deep, well to excessively drained sands and gravels with high water transmission rates (**0.30 in./hr.**). Group **A** soils include **sand, loamy sand,** or **sandy loam**.

Group B: Soils with moderately low runoff potential due to moderate infiltration rates when thoroughly wetted. These soils consist primarily of moderately deep to deep, and moderately well to well-drained soils. Group **B** soils have moderate water transmission rates (**0.15-0.30 in./hr.**) and include **silt loam or loam**.

Group C: Soils with moderately high runoff potential due to slow infiltration rates when thoroughly wetted. These soils typically have a layer near the surface that impedes the downward movement of water or soils. Group **C** soils have low water transmission rates (**0.05-0.15 in./hr.**) and include **sandy clay loam**.

Group D: Soils with high runoff potential due to very slow infiltration rates. These soils consist primarily of clays with high swelling potential, soils with permanently high water tables, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious parent material. Group **D** soils have very low water transmission rates (**0-0.05 in./hr.**) and include **clay loam**, **silty clay loam**, **sandy clay**, **silty clay**, or **clay**.

Any disturbance of a soil profile can significantly alter the soil's infiltration characteristics. With urbanization, the hydrologic soil group for a given area can change due to soil mixing, introduction of fill material from other areas, removal of material during mass grading operations, or compaction from construction equipment. A layer of topsoil may typically be saved and replaced after the earthwork is completed, but the native underlying soils have been dramatically altered. **Therefore, any disturbed soil should be classified by its physical characteristics** as given above for each soil group.

Some jurisdictions require all site developments to be analyzed using an ***HSG*** classification that is one category below the actual pre-developed ***HSG***. For example, a site with a pre-developed ***HSG*** classification of ***B***, as determined from the soil survey, would be analyzed in its developed state using an ***HSG*** classification of ***C***.

B. Hydrologic Condition

Hydrologic condition represents the effects of ***cover type*** and ***treatment*** on infiltration and runoff. It is generally estimated from the density of plant and residue cover across the drainage area. ***Good hydrologic condition*** indicates that the cover has a low runoff potential, while ***poor hydrologic condition*** indicates that the cover has a high runoff potential. ***Hydrologic condition*** is used in describing non-urbanized lands such as woods, meadow, brush, agricultural land, and open spaces associated with urbanized areas, such as lawns, parks, golf courses, and cemeteries. ***Treatment*** is a cover type modifier to describe the management of cultivated agricultural lands. **Table 4-6(a,b)** provides an excerpt from Table 2-2 in <u>TR-55</u> which shows the treatment and hydrologic condition for various land uses.

When a watershed is being analyzed to determine the impact of proposed development, Virginia's stormwater management regulations require the designer to consider all existing or undeveloped land to be in *hydrologically good condition*. This results in lower existing condition peak runoff rates which, in turn, results in greater post-development peak control. In most cases, undeveloped land is in good hydrologic condition unless it has been altered in some way. Since the goal of most stormwater programs is to reduce the peak flows from developed or altered areas to their pre-developed or pre-altered rates, this is a reasonable approach. In addition this approach eliminates any inconsistencies in judging the condition of undeveloped land or open space.

C. Runoff Curve Number (CN) Determination

The soil group classification, cover type and the hydrologic condition are used to determine the runoff curve number, ***CN***. The *CN* indicates the runoff potential of an area when the ground is not frozen. **Table 4-6(a,b)**, excerpted from TR-55,provides the *RCNs* for various land use types and soil groups. (A more complete table can be found in TR-55.)

Several factors should be considered when choosing an *CN* for a given land use. First, the designer should realize that the curve numbers in **Table 4-6** and TR-55 are for the ***average antecedent runoff*** or ***moisture condition***, ***ARC***. The *ARC* is the index of runoff potential before a storm event and can have a major impact on the relationship between rainfall and runoff for a watershed. Average *ARC* implies that the soils are neither very wet nor very dry when the design storm begins. Average *ARC* runoff curve numbers can be converted to dry or wet values, however the average antecedent runoff condition is recommended for design purposes.

A decision to use "wet" or "dry" antecedent runoff conditions should be based on thorough field work, such as carefully monitored rain gauge data.

It is also important to consider the list of assumptions made in developing the runoff curve numbers as provided in **Table 4-6** and in TR-55. Some of these assumptions are outlined below.

TABLE 4 - 6a

Runoff Curve Numbers for Urban Areas [1]

*Adapted from TR-55 Table 2-2a. --Runoff Curve Numbers for Urban Areas**

Cover Description		Curve Numbers for Hydrologic Soil Group:			
Cover Type and Hydrologic Condition	**Average percent impervious area[2]**	**A**	**B**	**C**	**D**
Fully developed urban areas (vegetation established) :					
Open space (lawns, parks, golf courses, cemeteries, etc.)[2]:					
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
½ acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas:					
Newly graded areas (pervious areas only, no vegetation)[2]		77	86	91	94
Idle lands (CN's are determined using cover types similar to those in TR-55 Table 2-2c).					

**Average runoff condition and $I_a = 0.2S$*

[1]Refer to TR-55 for additional cover types and general assumptions and limitations.
[2]For specific footnotes, see TR-55 ***Table 2-2a.***

TABLE 4 - 6b
Runoff Curve Numbers for Agricultural Areas[1]

Adapted from TR-55 Table 2-2b-- Runoff Curve Numbers for Other Agricultural Lands[*]					
Cover Description		**Curve Numbers for Hydrologic Soil Group:**			
Cover Type	**Hydrologic Condition**	**A**	**B**	**C**	**D**
Pasture, grassland, or range - continuous forage for grazing [2].	Good	39	61	74	80
Meadow - continuous grass, protected from grazing and generally mowed for hay . . .	----	30	58	71	78
Brush - brush-weed-grass mixture with brush the major element[2]	Good	[2]30	48	65	73
Woods - grass combination (orchard or tree farm)[2]	Good	32	58	72	79
Woods [2]	Good	[2]30	55	70	77
Farmsteads - buildings, lanes, driveways, and surrounding lots.	----	59	74	82	86

**Average runoff condition and $I_a = 0.2S$*

[1]Refer to TR-55 for additional cover types and general assumptions and limitations.
*[2]For specific footnotes, see TR-55 **Table 2-2b**.*

RCN Determination Assumptions (TR-55):

1. *The urban curve numbers, for such land uses as residential, commercial, and industrial, are computed with the percentage of impervious area as shown. A composite curve number should be re-computed using the actual percentage of imperviousness if it differs from the value shown.*

2. *The impervious areas are directly connected to the drainage system.*

3. *Impervious areas have a runoff curve number of 98.*

4. *Pervious areas are considered equivalent to open space in good hydrologic condition.*

These assumptions, as well as others, are footnoted in TR-55, Table 2-2. **TR-55 provides a graphical solution for modification of the given *RCNs* if any of these assumptions do not hold true**.

The designer should become familiar with the definition of ***connected*** versus ***unconnected*** impervious areas along with the graphical solutions and the impact that their use can have on the resulting *RCN*. After some experience in using this section of TR-55, the designer will be able to make field evaluations of the various criteria used in the determination of the *RCN* for a given site. In addition, the designer will need to determine if the watershed contains sufficient diversity in land use to justify dividing the watershed into several sub-watersheds. If a watershed or drainage area cannot be adequately described by one weighted curve number, then the designer must divide the watershed into sub-areas and analyze each one individually, generate individual hydrographs, and add those hydrographs together to determine the composite peak discharge for the entire watershed.

Figure 4-11 shows the decision making process for analyzing a drainage area. The flow chart can be used to select the appropriate tables or figures in TR-55 from which to then choose the runoff curve numbers. Worksheet 2 in TR-55 is then used to compute the weighted curve number for the area or sub-area.

D. The Runoff Equation

The SCS runoff equation is used to solve for runoff as a function of the initial abstraction, I_a, and the potential maximum retention, S, of a watershed, both of which are functions of the *RCN*. This equation attempts to quantify all the losses before runoff begins, including infiltration, evaporation, depression storage, and water intercepted by vegetation.

TR-55 provides a graphical solution for the runoff equation. The graphical solution is found in Chapter 2 of TR-55: Estimating Runoff. Both the equation and graphical solution solve for the depth of runoff that can be expected from a watershed or sub-watershed, of a specified *RCN*, for any given frequency storm. Additional information can be found in the USDA-SCS National Engineering Handbook, Section 4.

These procedures, by providing the basic relationship between rainfall and runoff, are the basis for any hydrological study based on SCS methodology. Therefore, it is essential that the designer conduct a thorough site visit and consider all the site features and characteristics, such as soil types and hydrologic condition, when analyzing a watershed or drainage area.

E. Time of Concentration and Travel Time

The time of concentration, t_c, is the length of time required for a drop of water to travel from the most hydraulically distant point in the watershed or sub-watershed to the point of analysis. The travel time, T_t, is the time it takes that same drop of water to travel from the study point at the bottom of the sub-watershed to the study point at the bottom of the whole watershed. The travel time, T_t, is descriptive of the sub-watershed by providing its location relative to the study point of the entire watershed.

Similar to the rational method, the time of concentration, t_c, plays an important role in developing the peak discharge for a watershed. **Urbanization usually decreases the t_c, which results in an increase in peak discharge**. For this reason, to accurately model the watershed, the designer must be aware of any conditions which may act to decrease the flow time, such as channelization and channel improvements. On the other hand, the designer must also be aware of the conditions within the watershed which may actually lengthen the flow time, such as surface ponding above undersized conveyance systems and culverts.

1. Heterogeneous Watersheds

A heterogeneous watershed is one that has two or more hydrologically-defined drainage areas of differing land uses, hydrologic conditions, times of concentration, or other runoff characteristics, contributing to the study point. Quite often, development will turn a homogeneous watershed into a heterogeneous one. **Example 1** from **Chapter 6** provides an example of such a case.

Example 1 presents a heterogeneous watershed (in the developed condition) that generates a majority of its runoff from a portion of the watershed that does not contain the most hydrologically distant flow path. Therefore, the development has a very minor impact on the time of concentration. Since the longest t_c flow path is not representative of the peak flows from the area that contributes the majority of the total peak discharge to the study point, an alternate flow path should be selected that accurately reflects the timing and volume of the peak flow. **Figure 4-12** shows a schematic of the **Example 1** watershed, pre- and post-developed conditions. Note the location of the pre-developed t_c flow path and the minimal impact that development has on it.

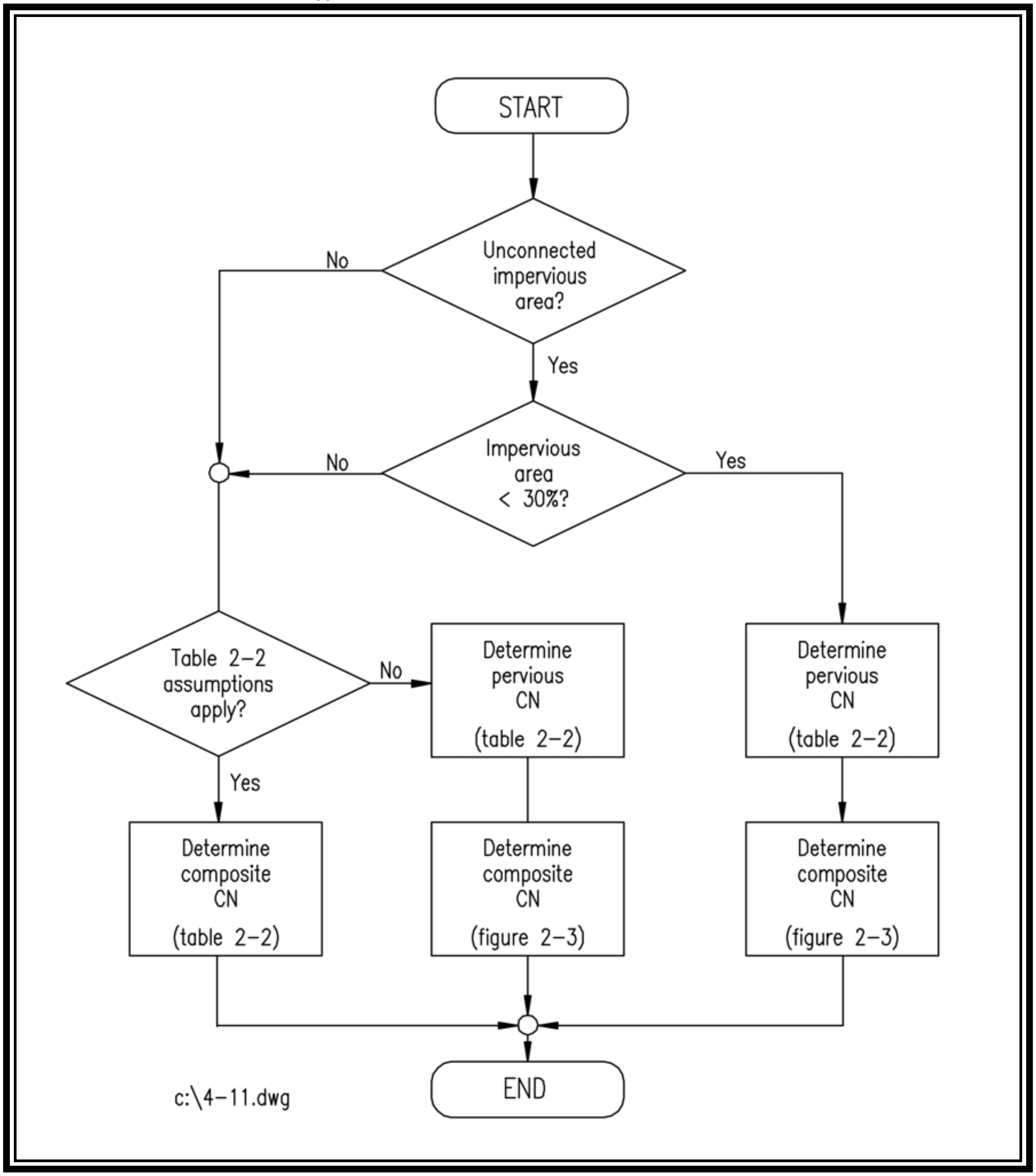
Table 4-7 gives a summary of the **post-developed** hydrologic data for **Example 1**, with the t_c flow path computed three different ways:

1. The entire watershed considered as one homogeneous watershed with the t_c flow path representing the most hydraulically distant point.

2. The entire watershed considered as one homogeneous watershed with the t_c flow path adjusted to reflect the flow from the developed area.

3. The watershed divided into two sub-watersheds and their peak flow hydrographs added together at the study point.

FIGURE 4 - 11
Runoff Curve Number Selection Flow Chart



Source: SCS TR-55 - Urban Hydrology for Small Watersheds

TABLE 4 - 7
Hydrologic Summary - Example 1

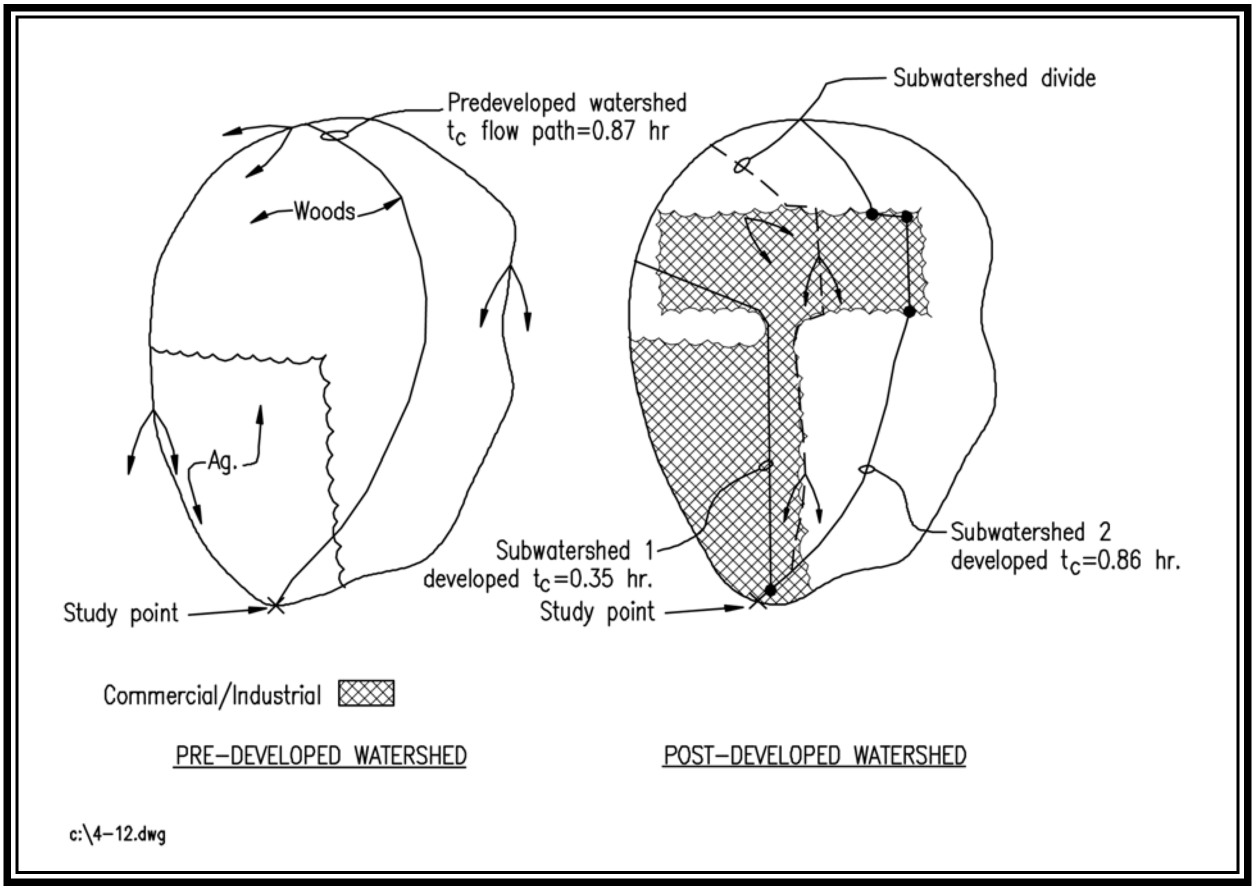
WATERSHED CONDITION	*RCN*	t_c *(hr.)*	Q_2 *(cfs)*
1. Homogeneous Watershed[1] Post-Developed	75	0.86	18.3
2. Homogeneous Watershed[1] Post-Developed (Adjusted T_c Path)	75	0.35	29.9
3. Sub-Watershed 1[2]	84	0.35	21.9
Sub-Watershed 2	67	0.86	7.2
COMBINED:			26.2

Notes: 1. Conditions 1 and 2 were computed using the TR-55 graphical peak discharge method.
2. Condition 3 was computed, and hydrographs added together, using the TR-55 Tabular hydrograph method.

Refer to ***Chapter 6, Example 1*** *for completed worksheets.*

Note that the combined peak discharge (Condition #1, using the TR-55 tabular method) for sub-watersheds 1 and 2 is smaller than the sum of their individual peaks (Condition #3). This occurs because their peak flows do not coincide simultaneously at the study point, per the t_c determination. **Example 1** illustrates the impact of the t_c flow path selection on a given study point for **any** watershed being examined for the effects of development. The second (or third) method in **Table 4-7** is the most representative of the impacts to the watershed for this particular example. **The flow path should be carefully selected to accurately reflect the development within a watershed and the resulting peak discharge.** See **Section 4-4.5** for details on the TR-55 tabular method, and **Chapter 6** for **Example 1** TR-55 worksheets.

FIGURE 4 - 12
Pre- and Post-Developed Watersheds - Example 1



2. Flow Segments

The time of concentration is the sum of the time increments for each flow segment present in the t_c flow path, such as ***overland*** or ***sheet flow***, ***shallow concentrated flow***, and ***channel flow***. These flow types are influenced by surface roughness, channel shape, flow patterns, and slope, and are discussed below:

a. ***Overland (sheet) flow*** is shallow flow over plane surfaces. For the purposes of determining time of concentration, overland flow usually exists in the upper reaches of the hydraulic flow path.

TR-55 utilizes Manning's kinematic solution to compute t_c for overland sheet flow. The roughness coefficient is the primary culprit in the misapplication of the kinematic t_c equation. Care should be taken to accurately identify the surface conditions for overland flow. **Table 4-9(a)** in this handbook and Table 3-1 in TR-55 provide selected coefficients for various surface conditions. Refer to TR-55 and Examples in **Chapter 6** for the use of Mannings Kinematic Equation.

NOTE: *Sheet flow can influence the peak discharge of small watersheds dramatically because the ratio of flow length to flow velocity is usually very high.* ***Surface roughness, soil types, and slope will dictate the distance before sheet flow transitions into shallow concentrated flow****. TR-55 stipulates that the maximum length of sheet flow is 300 feet. Many hydrologists and geologists will argue that, based on the definition of sheet flow, that 100 to 150 feet is the maximum distance before the combination of quantity and velocity create shallow concentrated flow. In an urban application (usually a relatively small drainage area), the flow time associated with 300 feet of sheet flow will result in a disproportionately large segment of the total time of concentration for the watershed. This will result in a very slow overall* t_c *, and may not be representative of the drainage area as a whole.* ***As stated previously, the designer must be sure that the flow path chosen is not only representative of the drainage area, but also is the flow path for the significant portion of the total peak discharge****.*

Notice that in **Example 1**, the majority of the pre- and post-developed condition t_c flow time for the watershed is overland sheet flow. **Table 4-8** computes the t_c for **Example 1**, (total $t_c = 0.87$ *hrs*., overland sheet flow = *0.75 hrs*.) **Table 4-8** also shows the sensitivity of the peak discharge to adjustments in the Manning's roughness coefficient, *n*, for overland sheet flow. Note that the manipulation of the roughness coefficient can have a significant impact on the computed discharge. This illustrates the need for accurate watershed condition data. An on-site investigation should be completed to determine actual land cover conditions, or the designer should state that assumed values are being used. **Careful selection of the surface roughness coefficient is essential to calculate an accurate t_c and peak discharge**.

TABLE 4 - 8

T_c and Peak Discharge Sensitivity to Overland Sheet Flow Roughness Coefficients

Description	**Manning's *'n'***	**Overland Sheet Flow Time* *(hrs.)***	**Pre-Developed Total Time of Concentration, t_c *(hrs.)***	**2-Yr. Pre-Developed Peak Discharge** *(cfs)***
Woods - Light Underbrush	.40	0.75	0.87	8.5
Rangeland-Natural	.13	0.31	0.43	15.0
Woods - Dense Underbrush	.80	1.31	1.43	6.0

* *overland flow time calculated using Manning's kinematic solution (TR-55)*
** *peak discharge computed using Example 6.1 hydrology*

b. ***Shallow Concentrated Flow*** usually begins where overland flow converges to form small rills or gullies. Shallow concentrated flow can exist in small manmade drainage ditches (paved and unpaved) and in curb and gutters.

TR-55 provides a graphical solution for shallow concentrated flow. The input information needed to solve for this flow segment is the land slope and the surface condition (paved or unpaved).

c. ***Channel flow*** occurs where flow converges in gullies, ditches or swales, and natural or manmade water conveyances (including storm drainage pipes). Channel flow is assumed to exist in perennial streams or wherever there is a well-defined channel cross-section.

The Manning Equation is used for open channel flow and pipe flow, and usually assumes full flow or bank-full velocity. Manning coefficients can be found in **Table 4-9(b-d)** for open channel flow (natural and man-made channels) and closed channel flow. Coefficients can also be obtained from standard textbooks such as Open Channel Hydraulics or Handbook of Hydraulics.

TABLE 4 - 9a

Roughness Coefficient 'n' for the Manning Equation - Sheet Flow

Surface Description	**'*n*' Value**
Smooth Surfaces (Concrete, Asphalt, Gravel, or Bare Soil	0.011
Fallow (No Residue)	0.05
Cultivated Soils:	
Residue Cover < 20%	0.06
Residue Cover > 20%	0.17
Grass:	
Short Grass Prairie	0.15
Dense Grasses[2]	0.24
Bermuda grass	0.41
Range (Natural)	0.13
Woods:[3]	
Light Underbrush	0.40
Dense Underbrush	0.80

[1] The 'n' values are composite of information compiled by Engman (1986).
[2] Includes species such as weeping lovegrass, bluegrass, buffalo grass, blue grama grass, and native grass mixtures.
[3] When selecting n, consider cover to a height of about 0.1 ft. This is the only part of the plant cover that will obstruct sheet flow.

From 210-VI-TR-55, Second Edition, June 1986

TABLE 4 - 9b
Roughness Coefficient 'n' for the Manning Equation - Pipe Flow

Material	'*n*' Value Range	
	From	To
Coated Cast-iron	0.010	0.014
Uncoated Cast-iron	0.011	0.015
Vitrified Sewer Pipe	0.010	0.017
Concrete Pipe	0.010	0.017
Common Clay Drainage Tile	0.011	0.017
Corrugated Metal (2 2/3 x ½)	0.023	0.026
Corrugated Metal (3 x 1 and 6 x 1)	0.026	0.029
Corrugated Metal (6 x 2 Structural Plate)	0.030	0.033

Source: Handbook of Hydraulics, Sixth Edition, Brater & King

TABLE 4 - 9c

Roughness Coefficient 'n' for the Manning Equation - Constructed Channels

Lining Material	'*n*' Value Range	
	From	To
Concrete Lined	0.012	0.016
Cement Rubble	0.017	0.025
Earth, Straight and Uniform	0.017	0.022
Rock Cuts, Smooth and Uniform	0.025	0.033
Rock Cuts, Jagged and Irregular	0.035	0.045
Winding, Sluggish Canals	0.022	0.027
Dredged Earth Channels	0.025	0.030
Canals with Rough Stony Beds, Weeds on Earth Banks	0.025	0.035
Earth Bottom, Rubble Sides	0.028	0.033
Small Grass Channels:		
Long Grass - 13"	0.042	
Short Grass - 3"	0.034	

Adapted from Handbook of Hydraulics, Sixth Edition, Brater & King

TABLE 4 - 9d

Roughness Coefficient 'n' for the Manning Equation - Natural Stream Channels

Channel Lining	'*n*' Value Range	
	From	To
1. Clean, Straight Bank, Full Stage, No Rifts or Deep Pools	0.025	0.030
2. Same as #1, But Some Weeds and Stones	0.030	0.035
3. Winding, Some Pools and Shoals, Clean	0.033	0.040
4. Same as #3, Lower Stages, More Ineffective Slope and Sections	0.040	0.050
5. Same as #3, Some Weeds and Stones	0.035	0.045
6. Same as #4, Stony Sections	0.045	0.055
7. Sluggish River Reaches, Rather Weedy with Very Deep Pools	0.050	0.070
8. Very Weedy Reaches	0.075	0.125

Adapted from Handbook of Hydraulics, Sixth Edition, Brater & King

4-4.4 TR-55 Graphical Peak Discharge Method

The ***graphical peak discharge method*** was developed from hydrograph analyses using TR-20, Computer Program for Project Formulation-Hydrology (SCS, 1983). The graphical method develops the peak discharge in cubic feet per second(cfs) for a given watershed.

4-4.4.1 Limitations

There are several limitations that the designer should be aware of before using the TR-55 graphical method:

1. *The watershed being studied must be hydrologically homogeneous, i.e., the land use, soils, and cover are distributed uniformly throughout the watershed and can be described by one curve number.*

2. *The watershed may have only one main stream or flow path. If more than one is present they must have nearly equal t_c's so that the entire watershed is represented by one t_c .*

3. *The analysis of the watershed cannot be part of a larger watershed study which would require adding hydrographs since the graphical method does not generate a hydrograph.*

4. *For the same reason, the graphical method should not be used if a runoff hydrograph is to be routed through a control structure.*

5. *When the initial abstraction - rainfall ratio (I_a / P) falls outside the range of the Unit Peak Discharge curves (0.1 to 0.5), the limiting value of the curve must be used.*

The reader is encouraged to review the TR-55 Manual to become familiar with these and other limitations associated with the graphical method.

The graphical method can be used as a planning tool to determine the impact of development or land use changes within a watershed, or to anticipate or predict the need for stormwater management facilities or conveyance improvements. Sometimes, the graphical method can be used in conjunction with the TR-55 short-cut method for estimating the storage volume required for post-developed peak discharge control. This short-cut method is found in Chapter 6 of TR-55 and is discussed in **Chapter 5** of this handbook. However, it should be noted that a more sophisticated computer model such as TR-20 or HEC-1, or even TR-55 Tabular Hydrograph Method, should be used for analyzing complex, urbanizing watersheds.

4-4.4.2 Information Needed

The following represents a brief list of the parameters needed to compute the peak discharge of a watershed using the TR-55 Graphical Peak Discharge Method. For a detailed explanation of the terms listed, refer to **Section 4-4.4.3** in this handbook.

1. *The drainage area, in square miles*
2. t_c *, in hours*
3. *Weighted runoff curve number, CN*
4. *Rainfall amount, P, for specified design storm, in inches*
5. *Total runoff, Q, in inches (see runoff equation, TR-55)*
6. *Initial abstraction,* I_a *, for each subarea*
7. *Ratio of* I_a / P *for each subarea*
8. *Rainfall distribution (Type I, IA, II or III)*

4-4.4.3 Design Parameters

The TR-55 ***peak discharge equation*** is:

$$q_p = q_u A_m Q F_p$$

Equation 4-3
TR-55 Peak Discharge Equation

where:

q_p = *peak discharge, cfs*
q_u = *unit peak discharge, cfs/mi²/in (csm/in)*
A_m = *drainage area, mi²*
Q = *runoff, in inches, and*
F_p = *pond and swamp adjustment factor*

All the required information has been determined earlier except for the unit peak discharge, q_u , and the pond and swamp adjustment factor, F_p.

The unit peak discharge, q_u , is a function of the initial abstraction, I_a , precipitation, P, and the time of concentration, t_c , and can be determined from the Unit Peak Discharge Curves in TR-55. The unit peak discharge is expressed in *cubic feet per second per square mile per inch of runoff.*

Initial abstraction, as indicated previously, is a measure of all the losses that occur before runoff begins, including infiltration, evaporation, depression storage, and water intercepted by vegetation, and can be calculated from empirical equations or Table 4-1 in TR-55.

The pond and swamp adjustment factor is an adjustment in the peak discharge to account for pond and swamp areas if they are spread throughout the watershed and are not considered in the t_c computation. Refer to TR-55 for more information on pond and swamp adjustment factors.

The unit peak discharge, q_u , is obtained by using t_c and the I_a /P ratio with Exhibit 4-I, 4-IA, 4-II, or 4-III (depending on the rainfall distribution type) in TR-55. As limitation number 5 above indicates, the ratio of I_a /P must fall between 0.1 and 0.5. The designer must use the limiting value on the curves when the computed value is not within this range. The unit peak discharge is determined from these curves and entered into the above equation to calculate the peak discharge.

4-4.5 TR-55 Tabular Hydrograph Method

The ***tabular hydrograph method*** can be used to analyze large heterogeneous watersheds. The tabular method can develop partial composite flood hydrographs at any point in a watershed by dividing the watershed into homogeneous subareas. The method is especially applicable for estimating the effects of land use change in a portion of a watershed.

The tabular hydrograph method provides a tool to efficiently analyze several sub-watersheds to verify the combined impact at a downstream study point. It is especially useful to verify the timing of peak discharges. Sometimes, the use of detention in a lower sub-watershed may actually increase the combined peak discharge at the study point. This procedure allows a quick check to verify the timing of the peak flows and to decide if a more detailed study is necessary.

4-4.5.1 Limitations

The following represents some of the basic limitations that the designer should be aware of before using the TR-55 tabular method:

1. *The travel time, T_t , must be less than 3 hours (largest T_t in TR-55 , Exhibit 5).*

2. *The time of concentration, t_c , must be less than 2 hours (largest t_c in TR-55 , Exhibit 5).*

3. *The acreage of the individual sub-watersheds should not differ by a factor of 5 or more.*

When these limitations cannot be met, the designer should use the TR-20 computer program or other available computer models which will provide more accurate and detailed results.

The reader is encouraged to review the TR-55 manual to become familiar with these and other limitations associated with the tabular method.

4-4.5.2 Information Needed

The following represents a brief list of the parameters needed to compute the peak discharge of a watershed using the TR-55 Tabular method. For a detailed explanation of the terms listed, refer to **Section 4-4.4.3** in this handbook.

1. *Subdivision of the watershed into areas that are relatively homogeneous.*
2. *The drainage area of each subarea, in square miles.*
3. *Time of concentration, t_c , for each subarea in hours.*
4. *Travel time, T_t , for each routing reach, in hours.*
5. *Weighted runoff curve number, RCN, for each subarea.*
6. *Rainfall amount, P, in inches, for each specified design storm.*
7. *Total runoff, Q, in inches (see runoff equation, TR-55) for each subarea.*
8. *Initial abstraction, I_a , for each subarea.*
9. *Ratio of I_a /P for each subarea.*
10. *Rainfall distribution (I, IA, II or III)*

4-4.5.3 Design Parameters

The use of the tabular method requires that the designer determine the travel time through the entire watershed. As stated previously, the entire watershed is divided into smaller sub-watersheds that must be related to one another and to the whole watershed with respect to *time.* The result is that the time of peak discharge is known for any one sub-watershed relative to any other sub-watershed or for the entire watershed.

> ***Travel time***, T_t , represents the time for flow to travel from the study point at the bottom of a sub-watershed to the bottom of the entire watershed. This information must be compiled for each sub-watershed.

The data for up to 10 sub-watersheds can be compiled on one TR-55 worksheet. (TR-55 Worksheets 5a and 5b.)

To obtain the peak discharge using the *graphical method*, the unit peak discharge is read off of a curve. However, the *tabular method* provides this information in the form of a table of values, found in TR-55, Exhibit 5. These tables are arranged by rainfall type (I, IA, II, and III), I_a /*P*, t_c , and T_t . In most cases, the actual values for these variables, other than the rainfall type, will be different from the values shown in the table. Therefore, a system of rounding these values has been established in the TR-55 manual. The I_a/P term is simply rounded to the nearest table value. The t_c and T_t values are rounded together in a procedure that is outlined on pages 5-2 and 5-3 of the TR-55 manual. The accuracy of the computed peak discharge and time of peak discharge is highly dependent on the proper use of these procedures.

The following equation, along with the information compiled on TR-55 Worksheet 5b, is then used to determine the flow at any time:

$$q = q_t A_m Q$$

Equation 4-4
Tabular Hydrograph Peak Discharge Equation

where: *q = hydrograph coordinate in cfs, at hydrograph time t;*
q_t = tabular hydrograph unit discharge at hydrograph time t from TR-55 Exhibit 5, csm/in;
A_m = drainage area of individual subarea, mi^2; and
Q = runoff in.

The product $A_m Q$ is multiplied by each table value in the appropriate unit hydrograph in TR-55 Exhibit 5, (each sub-watershed may use a different unit hydrograph) to generate the actual hydrograph for the subwatershed. This hydrograph is tabulated on TR-55 worksheet 5b and then added together with the hydrographs from the other sub-watersheds, being careful to use the same time increment for each subwatershed. The result is a composite hydrograph at the bottom of the worksheet for the entire watershed. Refer to Example 1 in Chapter 6 for a completed analysis using the TR-55 tabular hydrograph method.

The preceding discussion on the Tabular Method is taken from TR-55 and is NOT complete. The designer should obtain a copy of TR-55 and learn the procedures and limitations as outlined in that document. Examples and worksheets are provided in TR-55 that lead the reader through the procedures for each chapter.

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CHAPTER 4

APPENDIX

APPENDIX 4A

Hydrologic Soil Groups in Virginia

The majority of soils found in Virginia along with their corresponding Hydrologic Soil Group designation are listed on the following pages. **All stormwater BMP designs that require specific soil conditions to be present should be based on an actual soils analysis.**

Soil Name	Hydgrp	Soil Name	Hydgrp	Soil Name	Hydgrp
APPOMATTOX	B	AQUENTS	D	AQUULTS	D
ARAPAHOE	B/D	ARCOLA	C	ARGENT	D
ASBURN*	C	ASHE	B	ASHLAR	B
ASSATEAGUE	A	ATKINS	D	ATLEE	C
AUGUSTA	C	AURA	B	AUSTINVILLE	B
AXIS	D	AYCOCK	B	BACKBAY	D
BADIN	B	BAILE	D	BAILEGAP	B
BAMA	B	BAYBORO	D	BEACHES	D
BECKHAM	B	BELHAVEN	D	BELTSVILLE	C
BELVOIR	C	BERKS	C	BERMUDIAN	B
BERTIE	B	BIBB	D	BILTMORE	A
BIRDSBORO	B	BLADEN	D	BLAIRTON	C
BLAND	C	BLEAKHILL	C	BLUEMONT*	B
BOHICKET	D	BOJAC	B	BOLLING	C
BOLTON	B	BONNEAU	A	BOOKWOOD	B
BOTETOURT	C	BOURNE	C	BOWMANSVILLE	B/D
BRADDOCK	B	BRADLEY	C	BRANDYWINE	C
BRECKNOCK	B	BREMO	C	BRENTSVILLE	C
BROADWAY	B	BROCKROAD	C	BRUSHY	B
BUCHANAN	C	BUCKHALL	B	BUCKS	B
BUCKTON	B	BUFFSTAT	B	BUGLEY	C/D
BUNCOMBE	A	BURKETOWN	C	BURROWSVILLE	C
CALVERTON	C	CALVIN	C	CAMOCCA	A/D
CANEYVILLE	C	CARBO	C	CARDIFF	B
CAROLINE	C	CARRVALE	D	CARTECAY	C
CATASKA	D	CATHARPIN	C	CATLETT	C/D
CATOCTIN	C	CATPOINT	A	CAVERNS	B
CECIL	B	CHAGRIN	B	CHAPANOKE	C

Soil Name	Hydgrp	Soil Name	Hydgrp	Soil Name	Hydgrp
CHASTAIN	D	CHATUGE	D	CHAVIES	B
CHENNEBY	C	CHESTER	B	CHEWACLA	C
CHICKAHOMINY	D	CHILHOWIE	C	CHINCOTEAGUE	D
CHIPLEY	C	CHISWELL	D	CHRISTIAN	C
CID	C	CLAPHAM*	C	CLEARBROOK	D
CLIFTON	C	CLUBCAF	D	CLYMER	D
COASTAL BEACH	D	CODORUS	C	COLFAX	C
COLLEEN	C	COLVARD	B	COMBS	B
COMUS	B	CONETOE	A	CONGAREE	B
COOSAW	B	COROLLA	D	CORYDON	D
COTACO	C	COURSEY	C	COWEE	B
COXVILLE	D	CRAIGSVILLE	B	CRAVEN	C
CREEDMOOR	C	CROTON	D	CULLEN	C
CULPEPER	C	DALEVILLE	D	DANDRIDGE	D
DAVIDSON	B	DAWHOO VARIANT	B/D	DECATUR	B
DEKALB	C	DELANCO	C	DELOSS	B/D
DERROC	B	DILLARD	C	DOGUE	C
DOROVAN	D	DOTHAN	B	DRAGSTON	C
DRALL	B	DRYPOND	D	DUCKSTON	A/D
DUFFIELD	B	DULLES	D	DUMFRIES	B
DUNBAR	D	DUNNING	D	DUPLIN	C
DURHAM	B	DYKE	B	EBBING	C
EDGEHILL	C	EDNEDYTOWN	B	EDNEYVILLE	B
EDOM	C	ELBERT	D	ELIOAK	C
ELSINBORO	B	EMPORIA	C	ENDCAV	C
ELIOK	C	ELKTON	C/D	ELLIBER	A

Soil Name	Hydgrp	Soil Name	Hydgrp	Soil Name	Hydgrp
ENON	C	ENOTT	C	ERNEST	C
EUBANKS	B	EULONIA	C	EUNOLA	C
EVANSHAM	D	EVARD	B	EVERGREEN	B
EXUM	C	FACEVILLE	B	FAIRFAX	B
FALLSINGTON	B/D	FAUGUIER	C	FAYWOOD	C
FEATHERSTONE	D	FISHERMAN	D	FLATWOODS	C
FLETCHER	B	FLUVANNA	C	FLUVAQUENTS	D
FORESTDALE	D	FORK	C	FRANKSTOWN	B
FREDERICK	B	FRENCH	C	FRIPP	A
GAILA	B	GAINESBORO	C	GALESTOWN	A
GEORGEVILLE	B	GILPIN	C	GLADEHILL	B
GLENELG	B	GLENVILLE	C	GLENWOOD	B
GOLDSBORO	B	GOLDSTON	C	GOLDVEIN	C
GORESVILLE*	B	GREENLEE	B	GRIMSLEY	B
GRITNEY	C	GROSECLOSE	C	GROVER	B
GUERNSEY	C	GULLION	C	GUNSTOCK	C
GUYAN	C	GWINNETT VARIENT	B	HAGERSTOWN	C
HALEWOOD	B	HARTLETON	B	HATBORO	D
HAWKSBILL	B	HAYESVILLE	B	HAYMARKET	D
HAYTER	B	HAYWOOD	B	HAZEL	C
HAZEL CHANNERY	C	HAZELTON	B	HELENA	C
HERNDON	B	HIWASSEE	B	HOADLY	C
HOBUCKEN	D	HOGELAND*	C	HOLLYWOOD	D
HUNTINGTON	B	HYATTSVILLE	B	HYDE	B/D
HYDRAQUENTS	B	INGLEDOVE	B	IREDELL	C/D

Soil Name	Hydgrp	Soil Name	Hydgrp	Soil Name	Hydgrp
IRONGATE	B	IUKA	C	IZAGORA	C
JACKLAND	D	JEDBURG	C	JEFFERSON	B
JOHNS	C	JOHNSTON	D	JUNALUSKA	B
KALMIA	B	KELLY	D	KEMPSVILLE	B
KENANSVILLE	A	KENANSVILLE VARIANT	C	KEYPORT	C
KINKORA	D	KINSTON	B/D	KLEJ	B
KLINESVILLE	C/D	KONNAROCK	C	LAIDIG	C
LAKEHURST VARIANT	A	LAKELAND	A	LANEXA	D
LANSDALE	B	LAROQUE	B	LAWNES	D
LEAF	D	LEAKSVILLE	D	LECK KILL	B
LEEDSVILLE*	B	LEETONIA	C	LEGORE	B
LEHEW	C	LENOIR	D	LEON	B/D
LEVY	D	LEW	B	LEWISBERRY	B
LIBRARY	D	LIGNUM	C	LILY	B
LINDSIDE	C	LITTLEJOE	B	LITZ	C
LLOYD	C	LOBDELL	B	LODI	B
LOUISA	B	LOUISBURG	B	LOWELL	C
LUCKETTS	B	LUCY	A	LUGNUM	C
LUMBEE	B/D	LUNT	C	LYNCHBURG	C
MACOVE	B	MADISON	B	MAGOTHA	D
MANASSAS	B	MANOR	B	MANTACHIE	C
MANTEO	C/D	MARBIE	C	MARGO	B
MARLBORO	B	MARR	B	MARUMSCO	C
MASADA	C	MASSANETTA	B	MASSANUTTEN	B
MATAPEAKE	B	MATNELFLAT	B	MATTAN	D

Soil Name	Hydgrp	Soil Name	Hydgrp	Soil Name	Hydgrp
MATTAPEX	C	MATTAPONI	C	MAURERTOWN	D
MAYODAN	B	MCGARY	C	MCQUEEN	C
MEADOWS	D	MEADOWVILLE	B	MECKLENBURG	C
MEGGETT	D	MELFA	D	MELVIN	D
MILLROCK	A	MINNIEVILLE	C	MIXED ALLUVIUM	D
MOLENA	A	MONACAN	C	MONGLE	C
MONONGAHELA	C	MONTALTO	C	MONTRESSOR*	B
MONTROSS	C	MOOMAW	C	MORRISONVILLE*	B
MORVEN	B	MOUNT LUCAS	C	MT WEATHER*	B
MUCKALEE	D	MUNDEN	B	MURRILL	B
MYATT	D	MYATT VARIANT	D	MYERSVILLE	B
NAHUNTA	C	NANSEMOND	C	NASON	B
NAWNEY	D	NEABSCO	C	NESTORIA	C/D
NEVARC	C	NEWARK	C	NEWBERN	C
NEWFLAT	D	NEWHAN	A	NEWMARC	C
NICHOLOSON	C	NIMMO	D	NIXA	C
NOLICHUCKY	B	NOLIN	B	NOMERVILLE	B
NORFOLK	B	OAKHILL	B	OAKLET	C
OATLANDS	B	OCCOQUAN	B	OCHLOCKONEE	B
OKEETEE	D	OPEQUON	C	ORANGE	D
ORANGEBURG	B	ORENDA	B	ORISKANY	B
OSIER	A/D	OTHELLO	C/D	PACOLET	B
PACTOLUS	A	PAGEBROOK	D	PAMLICO	D
PAMUNKEY	B	PAMUNKEY VARIANT	A	PANORAMA	B
PARKER	B	PARTLOW	D	PASQUOTANK	B/D
PEAKS	C	PEAWICK	D	PENN	C/D

Soil Name	Hydgrp	Soil Name	Hydgrp	Soil Name	Hydgrp
PHILO	B	PHILOMOMT*	B	PINEYWOODS	D
PINKSTON	B	PISGAH	C	POCATY	D
POCOMOKE	B/D	POINDEXTER	B	POLAWANA	A/D
POOLER VARIANT	D	POPE	B	POPLIMENTO	C
PORTERS	B	PORTSMOUTH	B/D	POUNCEY	D
PUNGO	D	PURCELLVILLE	B	PURDY	D
RABUM	B	RAINS	B/D	RAMSEY	D
RAPIDAN	B	RAPPHANNOCK	D	RARITAN	C
RAYNE	B	READINGTON	C	REAVILLE	C
REMLIK	A	RIGLEY	B	RION	B
RIVERVIEW	B	ROANOKE	D	ROHRERSVILLE	D
ROSS	B	ROWLAND	C	RUMFORD	B
RUSHTOWN	A	RUSTON	B	SAFELL	B
SASSAFRAS	B	SASSAFRAS	B	SAUNOOK	B
SAVANNAH	C	SCATTERSVILLE*	C	SCHAFFENAKER	A
SEABROOK	C	SEDGEFIELD	C	SEKIL	B
SENECA	B	SEQUOIA	C	SHELOCTA	B
SHENVAL	B	SHERANDO	B	SHEVA	C
SHOTTOWER	B	SINDION	B	SKETERVILLE	C
SLABTOWN	B	SLAGLE	C	SLICKENS	B
SNICKERSVILLE	B	SPEEDWELL	B	SPESSARD	A
SPIVEY	B	SPOSTSYLVANIA	C	SPRIGGS	C
SPRINGWOOD	B	STANTON	D	STARR	C
STATE	B	STEINSBURG	C	STONEVILLE	B
STUART	C	STUMPTOWN	B	SUCHES	B
SUDLEY	B	SUEQUEHANNA	D	SUFFOLK	B
SUSDLEY	B	SUSQUEHANNA	D	SWAMP	D

Soil Name	Hydgrp	Soil Name	Hydgrp	Soil Name	Hydgrp
SWEETAPPLE	B	SWIMLEY	C	SYCOLINE	D
SYLCO	C	SYLVATUS	D	TALLADEGA	C
TALLAPOOSA	C	TARBORO	A	TATE	B
TATUM	B	TETOTUM	C	THUNDER	B
THURMONT	B	TIDAL MARSH	D	TIMBERVILLE	B
TIOGA	B	TOCCOA	B	TODDSTAV	D
TOMOTLEY	B/D	TOMS	C	TORHUNTA	C
TOTIER	C	TOXAWAY	B/D	TRAPPIST	C
TREGO	B	TRENHOLM	D	TUCKAHOE	B
TUMBLING	B	TURBEVILLE	C	TUSQUITEE	B
TYGART	C	UCHEE	A	UDIFLUVENTS	B
UNISON	B	VANCE	C	VARINA	C
VAUCLUSE	C	VERTREES	B	WADESBORO	B
WAHEE	D	WAKULLA	A	WALLEN	B
WARMINSTER	C	WATAUGA	B	WATEREE	B
WATT	D	WAXPOOL	D	WEAVER	C
WEAVERTON*	C	WEBBTOWN	C	WEDOWEE	B
WEEKSVILLE	B/D	WEHADKEE	D	WEIKERT	C/D
WESTMORELAND	B	WESTON	D	WESTPHALIA	B
WEVERTON	B	WHEELING	B	WHITE STONE	D
WHITEFORD	B	WICKHAM	B	WILKES	C
WOLFGAP	B	WOODINGTON	B/D	WORSHAM	D
WRIGHTSBORO	C	WRYICK	B	WURNO	C
WYRICK	B	YADKIN	C/D	YEMASSEE	C
YEOPIM	B	YORK	C	ZEPP	B
ZION	C	ZOAR	C		

APPENDIX 4B

24-hour Rainfall Data for Virginia

24 HOUR RAINFALL DEPTHS

	YEAR						
COUNTY	1	2	5	10	25	50	100
Accomack	3.0	3.7	4.9	6.0	6.8	7.5	8.5
Albemarle	3.3	4.0	5.0	6.0	7.0	8.0	8.5
Alleghany	2.5	3.0	4.0	5.0	5.5	6.0	7.0
Amelia	3.0	3.5	4.5	5.5	6.0	7.0	7.5
Amherst	3.3	4.0	5.0	6.0	7.0	8.0	8.5
Appomattox	3.0	4.0	4.7	5.8	6.2	7.0	8.0
Augusta	3.0	4.0	4.5	5.5	6.5	7.2	8.0
Bath	2.5	3.0	4.0	5.0	5.5	6.0	7.0
Bedford	3.3	4.0	5.0	5.8	6.8	7.5	8.2
Bland	2.4	2.9	3.9	4.6	5.0	5.8	6.0
Botetourt	3.0	3.5	4.5	5.0	6.0	7.0	7.8
Brunswick	3.0	3.5	4.6	5.6	6.2	7.0	8.0
Buchanan	2.4	2.9	3.7	4.3	4.8	5.5	6.2
Buckingham	3.0	3.5	4.7	5.8	6.3	7.0	8.0
Campbell	3.0	3.7	4.7	5.8	6.3	7.0	7.9
Caroline	2.7	3.5	4.5	5.5	6.0	6.8	7.7
Carroll	2.8	3.2	4.0	4.9	5.2	6.0	6.8
Charles City	3.0	3.5	4.5	5.5	6.2	7.0	7.9
Charlotte	3.0	3.5	4.5	5.5	6.0	7.0	7.7
Chesapeake	3.2	3.8	5.1	6.0	7.0	8.0	8.9
Chesterfield	3.0	3.9	4.5	5.5	6.0	7.0	7.6
Clarke	2.7	3.1	4.5	5.0	6.0	7.0	7.6

COUNTY	1	2	5	10	25	50	100
			YEAR				
Craig	2.5	3.0	4.0	4.7	5.5	6.0	6.5
Culpeper	3.0	3.6	4.7	5.5	6.5	7.5	8.0
Cumberland	3.0	3.5	4.7	5.8	6.3	7.0	8.0
Dickenson	2.4	2.9	3.7	4.3	4.8	5.5	6.2
Dinwiddie	2.9	3.5	4.6	5.6	6.2	7.0	8.0
Essex	3.0	3.2	4.5	5.5	6.0	6.9	7.8
Fairfax	2.7	3.2	4.5	5.2	6.0	7.0	7.7
Fauquier	2.9	3.5	4.5	5.4	6.5	7.2	7.7
Floyd	3.0	3.3	4.3	5.0	5.5	6.2	7.0
Fluvanna	3.0	3.5	4.7	5.7	6.5	7.0	8.0
Franklin	3.3	3.7	4.7	5.7	6.0	7.0	8.0
Frederick	2.5	3.0	4.0	4.9	5.8	6.5	6.0
Giles	2.4	2.9	3.9	4.7	5.0	5.9	6.0
Gloucester	3.0	3.5	4.7	5.9	6.8	7.4	8.0
Goochland	3.0	3.5	4.7	5.7	6.5	7.0	8.0
Grayson	2.8	3.2	4.0	4.9	5.2	6.0	6.8
Greene	3.3	4.0	5.0	6.0	7.0	8.0	9.0
Greensville	3.0	3.5	4.7	5.6	6.5	7.2	8.0
Halifax	3.0	3.5	4.5	5.5	6.0	7.0	7.5
Hanover	2.8	3.3	4.5	5.5	6.0	6.9	7.6
Henrico	2.8	3.3	4.5	5.5	6.0	7.0	7.8
Henry	3.0	3.5	4.6	5.2	6.0	6.5	7.5
Highland	2.8	3.0	4.0	4.9	5.5	6.0	6.8

YEAR							
COUNTY	1	2	5	10	25	50	100
Isle of Wight	2.9	3.7	5.0	5.8	6.6	7.5	8.4
James City	2.8	3.5	4.7	5.8	6.4	7.2	8.0
King and Queen	2.8	3.4	4.5	5.7	6.2	7.0	7.9
King George	2.8	3.2	4.5	5.5	6.0	7.0	7.5
King William	2.8	3.4	4.5	5.7	6.2	7.0	7.9
Lancaster	2.8	3.5	4.7	5.7	6.5	7.2	8.0
Lee	2.7	3.0	3.7	4.5	5.0	5.6	6.0
Loudoun	3.0	3.3	4.5	5.2	6.0	6.9	7.5
Louisa	2.9	3.5	4.7	5.5	6.0	7.0	8.0
Lunenburg	2.9	3.5	4.5	5.5	6.0	7.0	7.5
Madison	3.3	4.0	5.0	6.0	7.0	8.0	9.0
Mathews	3.0	3.6	4.8	5.8	6.6	7.2	8.1
Mecklenburg	2.9	3.5	4.5	5.5	6.0	7.0	7.8
Middlesex	3.0	3.5	4.7	5.7	6.5	7.0	8.0
Montgomery	2.5	3.0	4.0	5.0	5.5	6.0	7.0
Nelson	3.3	4.0	5.0	6.0	7.0	8.0	8.5
New Kent	2.8	3.5	4.5	5.6	6.2	7.0	7.9
Northampton	3.1	3.7	5.0	6.0	6.8	7.6	8.6
Northumberland	2.8	3.5	4.7	5.7	6.5	7.2	8.0
Nottoway	3.0	3.5	4.5	5.5	6.0	7.0	7.9
Orange	3.2	3.5	4.7	5.5	6.5	7.5	8.0
Page	2.5	3.2	4.7	5.5	7.0	7.5	8.5
Patrick	2.8	3.5	4.5	5.0	5.8	6.2	7.3

	YEAR							
COUNTY	1	2	5	10	25	50	100	
Pittsylvania	2.8	3.5	4.5	5.2	6.2	6.7	7.5	
Powhatan	3.0	3.5	4.5	5.5	6.0	7.0	7.5	
Prince Edward	3.0	3.5	4.5	5.5	6.0	7.0	7.8	
Prince George		3.0	3.5	4.7	5.7	6.2	7.0	8.0
Prince William	3.0	3.5	4.S	5.3	6.0	7.0	7.8	
Pulaski	2.5	3.0	4.0	4.8	5.0	6.0	6.5	
Rappahannock	3.0	4.0	4.7	5.7	7.0	8.0	8.5	
Richmond	3.0	3.5	4.5	5.7	6.2	7.0	7.9	
Roanoke	3.0	3.5	4.5	5.0	6.0	6.7	7.5	
Rockbridge	3.0	3.5	4.5	5.5	6.2	7.0	8.0	
Rockingham	3.0	3.5	4.5	5.0	6.0	7.0	8.0	
Russell	2.5	3.0	3.8	4.4	5.0	5.5	6.0	
Scott	2.6	3.0	3.7	4.5	5.0	5.5	6.0	
Shenandoah	2.5	3.0	4.0	5.0	6.0	6.5	7.0	
Smyth	2.6	2.9	3.8	4.5	5.0	5.6	6.0	
Southampton	2.8	3.4	4.8	5.7	6.5	7.2	8.0	
Spotsylvania	3.1	3.5	4.5	5.5	6.0	7.0	7.5	
Stafford	2.9	3.5	4.5	5.5	6.0	7.0	7.5	
Suffolk	3.2	3.7	5.0	6.0	6.7	7.7	8.5	
Surry	2.8	3.4	4.8	5.7	6.5	7.2	8.0	
Sussex	2.8	3.4	4.8	5.7	6.5	7.2	8.0	
Tazewell	2.5	2.9	3.8	4.4	5.0	5.5	6.0	
Virginia Beach	3.0	3.8	5.0	6.0	7.0	8.0	9.0	

YEAR

COUNTY	1	2	5	10	25	50	100
Warren	2.8	3.5	4.5	5.1	6.5	7.0	8.0
Washington	2.6	3.0	3.8	4.5	5.0	5.6	6.0
Westmoreland	2.8	3.5	4.5	5.6	6.1	7.0	7.9
Wise	2.5	2.9	3.8	4.5	5.0	5.5	6.0
Wythe	2.6	2.9	3.8	4.6	5.0	5.8	6.0
York	3.0	3.7	4.8	6.0	6.6	7.4	8.2

APPENDIX 4C

Tabular Listing of Runoff Depths for Curve Numbers

(Available Upon Request)

CURVE
55

RUNOFF FOR INCHES OF RAINFALL

Tenths / Inches	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0										
1								0.00	0.00	0.01
2	0.02	0.02	0.04	0.05	0.07	0.08	0.10	0.12	0.15	0.17
3	0.19	0.22	0.25	0.28	0.31	0.35	0.38	0.42	0.45	0.49
4	0.53	0.57	0.61	0.65	0.70	0.74	0.79	0.83	0.88	0.93
5	0.98	1.03	1.08	1.13	1.19	1.24	1.29	1.35	1.40	1.46
6	1.52	1.58	1.63	1.69	1.75	1.81	1.87	1.94	2.00	2.06
7	2.12	2.19	2.25	2.32	2.38	2.45	2.51	2.58	2.65	2.72
8	2.78	2.85	2.92	2.99	3.06	3.13	3.20	3.27	3.34	3.42
9	3.49	3.56	3.63	3.71	3.78	3.85	3.93	4.00	4.08	4.15
10	4.23	4.30	4.38	4.46	4.53	4.61	4.69	4.76	4.84	4.92
11	5.00	5.08	5.15	5.23	5.31	5.39	5.47	5.55	5.63	5.71
12	5.79	5.87	5.95	6.03	6.12	6.20	6.28	6.36	6.44	6.53
13	6.61	6.69	6.77	6.86	6.94	7.02	7.11	7.19	7.27	7.36
14	7.44	7.53	7.61	7.69	7.78	7.86	7.95	8.03	8.12	8.20
15	8.29	8.38	8.46	8.55	8.63	8.72	8.81	8.89	8.98	9.07
16	9.15	9.24	9.33	9.41	9.50	9.59	9.68	9.76	9.85	9.94
17	10.03	10.11	10.20	10.29	10.38	10.47	10.56	10.64	10.73	10.82
18	10.91	11.00	11.09	11.18	11.27	11.36	11.45	11.53	11.62	11.71
19	11.80	11.89	11.98	12.07	12.16	12.25	12.34	12.43	12.52	12.61
20	12.70	12.80	12.89	12.98	13.07	13.16	13.25	13.34	13.43	13.52

NOTE: Runoff value determined by equation $Q = \frac{(P-0.2\,S)^2}{P+0.8\,S}$

REFERENCE: National Engineering Handbook, Section 4, HYDROLOGY

RAINFALL

CURVE

55

RUNOFF FOR INCHES OF RAINFALL

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
21	13.61	13.70	13.80	13.89	13.98	14.07	14.16	14.25	14.34	14.44
22	14.53	14.62	14.71	14.80	14.90	14.99	15.08	15.17	15.26	15.36
23	15.45	15.54	15.63	15.73	15.82	15.91	16.00	16.10	16.19	16.28
24	16.37	16.47	16.56	16.65	16.75	16.84	16.93	17.03	17.12	17.21
25	17.31	17.40	17.49	17.59	17.68	17.77	17.87	17.96	18.05	18.15
26	18.24	18.33	18.43	18.52	18.62	18.71	18.80	18.90	18.99	19.08
27	19.18	19.27	19.37	19.46	19.56	19.65	19.74	19.84	19.93	20.03
28	20.12	20.22	20.31	20.40	20.50	20.59	20.69	20.78	20.88	20.97
29	21.07	21.16	21.26	21.35	21.45	21.54	21.64	21.73	21.83	21.92
30	22.01	22.11	22.21	22.30	22.40	22.49	22.59	22.68	22.78	22.8[illegible]
31	22.97	23.06	23.16	23.25	23.35	23.44	23.54	23.63	23.73	23.82
32	23.92	24.02	24.11	24.21	24.30	24.40	24.49	24.59	24.68	24.78
33	24.88	24.97	25.07	25.16	25.26	25.35	25.45	25.55	25.64	25.74
34	25.83	25.93	26.03	26.12	26.22	26.31	26.41	26.51	26.60	26.70
35	26.79	26.89	26.99	27.08	27.18	27.28	27.37	27.47	27.56	27.66
36	27.76	27.85	27.95	28.05	28.14	28.24	28.33	28.43	28.53	28.62
37	28.72	28.82	28.91	29.01	29.11	29.20	29.30	29.40	29.49	29.59
38	29.69	29.78	29.88	29.98	30.07	30.17	30.27	30.36	30.46	30.56
39	30.65	30.75	30.85	30.94	31.04	31.14	31.23	31.33	31.43	31.52
40	31.62	31.72	31.82	31.91	32.01	32.11	32.20	32.30	32.40	32.49

NOTE: Runoff value determined by equation $Q = \frac{(P - 0.2\,S)^2}{P + 0.8\,S}$

REFERENCE: National Engineering Handbook, Section 4, HYDROLOGY

RAINFALL-RUNOFF DEPTHS FOR SELECTED RUNOFF CURVE NUMBERS

CURVE 95

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	0.00	0.00	0.01	0.05	0.11	0.17	0.24	0.32	0.40	0.48
1	0.56	0.65	0.74	0.83	0.92	1.01	1.11	1.20	1.30	1.39
2	1.48	1.58	1.68	1.78	1.87	1.97	2.07	2.16	2.26	2.36
3	2.44	2.54	2.64	2.74	2.84	2.93	3.03	3.13	3.23	3.32
4	3.42	3.52	3.62	3.72	3.82	3.92	4.02	4.12	4.21	4.31
5	4.41	4.51	4.61	4.71	4.81	4.91	5.01	5.11	5.21	5.30
6	5.40	5.50	5.60	5.70	5.80	5.90	6.00	6.10	6.20	6.30
7	6.40	6.50	6.60	6.70	6.80	6.90	7.00	7.10	7.19	7.29
8	7.39	7.49	7.59	7.69	7.79	7.89	7.99	8.09	8.19	8.29
9	8.39	8.49	8.59	8.69	8.79	8.89	8.99	9.09	9.19	9.29
10	9.39	9.49	9.59	9.69	9.79	9.89	9.99	10.09	10.19	10.29
11	10.39	10.49	10.59	10.69	10.79	10.89	10.99	11.09	11.19	11.29
12	11.39	11.49	11.59	11.69	11.79	11.89	11.99	12.09	12.19	12.29

CURVE 96

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	0.00	0.01	0.04	0.08	0.14	0.22	0.29	0.37	0.46	0.55
1	0.64	0.73	0.82	0.91	1.01	1.10	1.20	1.29	1.39	1.48
2	1.58	1.68	1.77	1.87	1.97	2.07	2.17	2.26	2.36	2.46
3	2.56	2.66	2.76	2.86	2.95	3.05	3.15	3.25	3.35	3.45
4	3.55	3.65	3.75	3.85	3.95	4.05	4.14	4.24	4.34	4.44
5	4.54	4.64	4.74	4.84	4.94	5.04	5.14	5.24	5.34	5.44
6	5.54	5.64	5.74	5.84	5.93	6.03	6.13	6.23	6.33	6.43
7	6.53	6.63	6.73	6.83	6.93	7.03	7.13	7.23	7.33	7.43
8	7.53	7.63	7.73	7.83	7.93	8.03	8.13	8.23	8.33	8.43
9	8.53	8.63	8.73	8.83	8.93	9.03	9.13	9.23	9.33	9.43
10	9.53	9.63	9.73	9.83	9.93	10.03	10.13	10.23	10.32	10.42
11	10.52	10.62	10.72	10.82	10.92	11.02	11.12	11.22	11.32	11.42
12	11.52	11.62	11.72	11.82	11.92	12.02	12.12	12.22	12.32	12.42

CURVE 97

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	0.00	0.00	0.04	0.11	0.18	0.26	0.35	0.44	0.53	0.62
1	0.71	0.81	0.90	1.00	1.10	1.19	1.29	1.39	1.49	1.58
2	1.68	1.78	1.88	1.98	2.08	2.17	2.27	2.37	2.47	2.57
3	2.67	2.77	2.87	2.97	3.07	3.16	3.26	3.36	3.46	3.56
4	3.66	3.76	3.86	3.96	4.06	4.16	4.26	4.36	4.46	4.56
5	4.66	4.76	4.86	4.96	5.06	5.16	5.26	5.36	5.46	5.55
6	5.65	5.75	5.85	5.95	6.05	6.15	6.25	6.35	6.45	6.55
7	6.65	6.75	6.85	6.95	7.05	7.15	7.25	7.35	7.45	7.55
8	7.65	7.75	7.85	7.95	8.05	8.15	8.25	8.35	8.45	8.55
9	8.65	8.75	8.85	8.95	9.05	9.15	9.25	9.35	9.45	9.55
10	9.65	9.75	9.85	9.95	10.05	10.15	10.25	10.35	10.45	10.55
11	10.65	10.75	10.85	10.95	11.05	11.15	11.25	11.35	11.45	11.55
12	11.65	11.75	11.85	11.95	12.05	12.15	12.25	12.35	12.45	12.55

Exhibit 2-7A

RAINFALL-RUNOFF DEPTHS FOR SELECTED RUNOFF CURVE NUMBERS

CURVE 92

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	0.0	0.00	0.00	0.02	0.05	0.09	0.14	0.20	0.26	0.33
1	0.41	0.48	0.56	0.64	0.72	0.80	0.89	0.97	1.06	1.15
2	1.24	1.33	1.42	1.51	1.60	1.69	1.78	1.88	1.98	2.07
3	2.16	2.26	2.35	2.45	2.54	2.64	2.74	2.83	2.93	3.02
4	3.12	3.22	3.31	3.41	3.51	3.60	3.70	3.80	3.90	4.00
5	4.09	4.19	4.29	4.39	4.48	4.58	4.68	4.78	4.88	4.97
6	5.07	5.17	5.27	5.37	5.47	5.56	5.66	5.76	5.86	5.96
7	6.06	6.15	6.25	6.35	6.45	6.55	6.65	6.75	6.85	6.95
8	7.05	7.15	7.25	7.34	7.44	7.54	7.64	7.74	7.84	7.94
9	8.04	8.14	8.24	8.33	8.43	8.53	8.63	8.73	8.83	8.93
10	9.03	9.13	9.23	9.33	9.43	9.53	9.63	9.73	9.83	9.93
11	10.03	10.13	10.23	10.33	10.42	10.52	10.62	10.72	10.82	10.92
12	11.02	11.12	11.22	11.32	11.42	11.52	11.62	11.72	11.82	11.92

CURVE 93

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	0.00	0.00	0.00	0.03	0.06	0.11	0.17	0.23	0.30	0.38
1	0.45	0.53	0.61	0.70	0.78	0.87	0.96	1.04	1.13	1.22
2	1.32	1.41	1.50	1.59	1.69	1.78	1.88	1.97	2.06	2.16
3	2.26	2.35	2.45	2.54	2.64	2.74	2.83	2.93	3.03	3.12
4	3.22	3.32	3.42	3.51	3.61	3.71	3.81	3.91	4.00	4.10
5	4.20	4.30	4.40	4.50	4.59	4.69	4.79	4.89	4.99	5.09
6	5.18	5.28	5.38	5.48	5.58	5.68	5.78	5.88	5.97	6.07
7	6.17	6.27	6.37	6.47	6.57	6.67	6.77	6.87	6.97	7.07
8	7.17	7.26	7.36	7.46	7.56	7.66	7.76	7.86	7.96	8.06
9	8.16	8.26	8.36	8.46	8.56	8.66	8.75	8.85	8.95	9.05
10	9.15	9.25	9.35	9.45	9.55	9.65	9.75	9.85	9.95	10.05
11	10.15	10.25	10.35	10.45	10.55	10.65	10.75	10.85	10.95	11.05
12	11.14	11.24	11.34	11.44	11.54	11.64	11.74	11.84	11.94	12.04

CURVE 94

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	0.00	0.00	0.01	0.04	0.08	0.14	0.20	0.27	0.34	0.42
1	0.50	0.58	0.67	0.76	0.84	0.93	1.02	1.11	1.21	1.30
2	1.39	1.49	1.58	1.68	1.77	1.87	1.97	2.06	2.15	2.24
3	2.35	2.44	2.54	2.64	2.73	2.83	2.93	3.03	3.13	3.22
4	3.32	3.42	3.52	3.62	3.72	3.81	3.91	4.01	4.11	4.21
5	4.30	4.40	4.50	4.60	4.70	4.80	4.90	5.00	5.10	5.19
6	5.29	5.39	5.49	5.59	5.69	5.79	5.89	5.99	6.09	6.18
7	6.28	6.38	6.48	6.58	6.68	6.78	6.88	6.98	7.08	7.18
8	7.27	7.37	7.47	7.57	7.67	7.77	7.87	7.97	8.07	8.17
9	8.27	8.37	8.47	8.57	8.67	8.77	8.87	8.97	9.07	9.17
10	9.27	9.37	9.47	9.57	9.67	9.77	9.87	9.97	10.07	10.17
11	10.27	10.37	10.47	10.57	10.66	10.76	10.86	10.96	11.06	11.16
12	11.26	11.36	11.46	11.56	11.66	11.76	11.86	11.96	12.06	12.16

Exhibit 2-7A

RAINFALL-RUNOFF DEPTHS FOR SELECTED RUNOFF CURVE NUMBERS

CURVE 89

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	0.00	0.00	0.00	0.00	0.02	0.04	0.08	0.12	0.17	0.22
1	0.28	0.35	0.41	0.48	0.55	0.63	0.71	0.78	0.86	0.94
2	1.03	1.11	1.19	1.28	1.37	1.46	1.54	1.63	1.72	1.81
3	1.90	1.99	2.08	2.17	2.26	2.36	2.45	2.54	2.64	2.73
4	2.82	2.92	3.01	3.11	3.20	3.30	3.39	3.49	3.58	3.68
5	3.77	3.87	3.96	4.06	4.16	4.25	4.35	4.45	4.54	4.64
6	4.74	4.83	4.93	5.02	5.12	5.22	5.32	5.42	5.51	5.61
7	5.71	5.80	5.90	6.00	6.10	6.20	6.30	6.39	6.49	6.59
8	6.69	6.79	6.88	6.98	7.08	7.18	7.28	7.38	7.47	7.57
9	7.67	7.77	7.87	7.97	8.06	8.16	8.26	8.36	8.46	8.56
10	8.66	8.76	8.86	8.95	9.05	9.15	9.25	9.35	9.45	9.55
11	9.65	9.75	9.84	9.94	10.04	10.14	10.24	10.34	10.44	10.54
12	10.64	10.73	10.83	10.93	11.03	11.13	11.23	11.33	11.43	11.53

CURVE 90

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	0.00	0.00	0.00	0.01	0.03	0.06	0.10	0.15	0.20	0.26
1	0.32	0.39	0.46	0.53	0.61	0.69	0.77	0.85	0.93	1.01
2	1.10	1.18	1.27	1.35	1.44	1.53	1.62	1.71	1.80	1.89
3	1.99	2.08	2.17	2.26	2.36	2.45	2.54	2.64	2.73	2.83
4	2.92	3.02	3.11	3.20	3.30	3.40	3.49	3.59	3.69	3.78
5	3.88	3.97	4.07	4.17	4.26	4.36	4.46	4.56	4.65	4.75
6	4.85	4.95	5.04	5.14	5.24	5.34	5.44	5.54	5.63	5.73
7	5.83	5.92	6.02	6.12	6.21	6.31	6.41	6.51	6.61	6.71
8	6.81	6.91	7.01	7.11	7.20	7.30	7.40	7.50	7.60	7.70
9	7.79	7.89	7.99	8.09	8.19	8.29	8.39	8.49	8.58	8.68
10	8.78	8.88	8.98	9.08	9.18	9.28	9.38	9.48	9.57	9.67
11	9.77	9.87	9.97	10.07	10.17	10.27	11.37	10.47	10.57	10.67
12	10.77	10.86	10.96	11.06	11.16	11.26	11.36	11.46	11.56	11.66

CURVE 91

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	0.00	0.00	0.00	0.01	0.03	0.07	0.12	0.17	0.23	0.29
1	0.36	0.43	0.50	0.58	0.66	0.74	0.82	0.91	0.99	1.08
2	1.17	1.25	1.34	1.43	1.52	1.61	1.70	1.80	1.89	1.98
3	2.07	2.16	2.26	2.35	2.44	2.54	2.63	2.73	2.83	2.92
4	3.02	3.11	3.21	3.30	3.40	3.50	3.59	3.69	3.79	3.89
5	3.99	4.08	4.17	4.27	4.37	4.47	4.56	4.66	4.76	4.86
6	4.96	5.05	5.15	5.25	5.34	5.44	5.54	5.64	5.74	5.84
7	5.94	6.04	6.14	6.24	6.34	6.44	6.53	6.63	6.73	6.83
8	6.93	7.03	7.13	7.23	7.33	7.43	7.52	7.62	7.72	7.82
9	7.92	8.02	8.12	8.22	8.31	8.41	8.51	8.61	8.71	8.81
10	8.91	9.01	9.11	9.21	9.31	9.41	9.51	9.61	9.71	9.80
11	9.90	10.00	10.10	10.20	10.30	10.40	10.50	10.60	10.70	10.80
12	10.89	10.99	11.09	11.19	11.29	11.39	11.49	11.59	11.69	11.79

Exhibit 2-7A

REFERENCE
SCS TR-16

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
ENGINEERING & WATERSHED PLANNING UNIT
BROOMALL, PENNSYLVANIA

TSC-NE-ENG.
220

2/70

RAINFALL-RUNOFF DEPTHS FOR SELECTED RUNOFF CURVE NUMBERS

CURVE 86

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	0.00	0.00	0.00	0.00	0.00	0.02	0.04	0.07	0.11	0.15
1	0.20	0.25	0.30	0.36	0.42	0.49	0.56	0.63	0.70	0.77
2	0.85	0.92	1.00	1.08	1.16	1.24	1.33	1.41	1.49	1.57
3	1.66	1.74	1.83	1.92	2.00	2.09	2.18	2.27	2.36	2.45
4	2.54	2.63	2.72	2.81	2.91	3.00	3.09	3.18	3.28	3.37
5	3.46	3.56	3.65	3.74	3.83	3.93	4.02	4.12	4.21	4.31
6	4.40	4.50	4.59	4.69	4.78	4.88	4.98	5.07	5.17	5.27
7	5.36	5.46	5.55	5.65	5.74	5.84	5.94	6.03	6.13	6.22
8	6.32	6.42	6.52	6.61	6.71	6.81	6.91	7.01	7.10	7.20
9	7.30	7.40	7.50	7.60	7.70	7.79	7.88	7.98	8.08	8.18
10	8.27	8.37	8.47	8.57	8.67	8.76	8.86	8.96	9.06	9.16
11	9.25	9.35	9.45	9.55	9.65	9.75	9.85	9.95	10.05	10.14
12	10.24	10.34	10.44	10.54	10.63	10.73	10.83	10.93	11.03	11.13

CURVE 87

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	0.00	0.00	0.00	0.00	0.00	0.02	0.05	0.08	0.13	0.17
1	0.22	0.28	0.34	0.40	0.47	0.54	0.61	0.69	0.75	0.83
2	0.91	0.98	1.06	1.15	1.23	1.31	1.39	1.47	1.56	1.65
3	1.74	1.83	1.92	2.01	2.09	2.18	2.27	2.36	2.45	2.55
4	2.64	2.73	2.82	2.91	3.01	3.10	3.19	3.28	3.38	3.47
5	3.57	3.67	3.76	3.85	3.95	4.04	4.13	4.23	4.32	4.42
6	4.51	4.61	4.71	4.80	4.90	5.00	5.09	5.19	5.29	5.38
7	5.48	5.58	5.67	5.77	5.87	5.97	6.06	6.16	6.25	6.35
8	6.45	6.55	6.64	6.74	5.84	6.94	7.03	7.13	7.23	7.33
9	7.43	7.52	7.62	7.72	7.81	7.91	8.01	8.11	8.21	8.31
10	8.41	8.51	8.61	8.70	8.80	8.90	9.00	9.10	9.20	9.30
11	9.39	9.49	9.59	9.69	9.78	9.88	9.98	10.08	10.18	10.28
12	10.38	10.47	10.57	10.67	10.77	10.87	10.97	11.07	11.17	11.27

CURVE 88

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	0.00	0.00	0.00	0.00	0.01	0.03	0.06	0.10	0.15	0.20
1	0.25	0.31	0.38	0.44	0.51	0.58	0.65	0.73	0.81	0.88
2	0.96	1.04	1.12	1.21	1.30	1.38	1.47	1.55	1.64	1.73
3	1.82	1.90	1.99	2.08	2.17	2.26	2.35	2.44	2.54	2.63
4	2.72	2.82	2.91	3.00	3.10	3.19	3.29	3.38	3.47	3.57
5	3.66	3.76	3.85	3.95	4.05	4.14	4.23	4.33	4.42	4.52
6	4.62	4.72	4.81	4.91	5.01	5.10	5.20	5.29	5.39	5.49
7	5.58	5.68	5.78	5.88	5.97	6.07	6.17	6.27	6.36	6.46
8	6.56	6.66	6.75	6.85	6.95	7.05	7.15	7.24	7.34	7.44
9	7.54	7.64	7.73	7.83	7.93	8.03	8.13	8.23	8.33	8.43
10	8.53	8.63	8.73	8.83	8.93	9.03	9.12	9.22	9.32	9.42
11	9.51	9.61	9.71	9.81	9.91	10.01	10.11	10.20	10.30	10.40
12	10.50	10.39	10.69	10.79	10.89	10.99	11.09	11.19	11.29	11.39

Exhibit 2-7A

RAINFALL-RUNOFF DEPTHS FOR SELECTED RUNOFF CURVE NUMBERS

CURVE 83

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.04	0.06	0.09
1	0.13	0.17	0.22	0.27	0.32	0.38	0.44	0.50	0.56	0.63
2	0.70	0.76	0.83	0.91	0.98	1.06	1.13	1.21	1.29	1.37
3	1.45	1.53	1.61	1.69	1.77	1.86	1.94	2.03	2.11	2.20
4	2.29	2.37	2.46	2.55	2.64	2.73	2.82	2.91	3.00	3.08
5	3.17	3.26	3.35	3.45	3.54	3.63	3.72	3.81	3.90	4.00
6	4.09	4.18	4.28	4.37	4.46	4.55	4.65	4.74	4.84	4.93
7	5.02	5.12	5.21	5.31	5.40	5.50	5.60	5.69	5.78	5.88
8	5.98	6.07	6.17	6.26	6.36	6.45	6.55	6.65	6.74	6.84
9	6.93	7.03	7.13	7.22	7.32	7.42	7.51	7.61	7.71	7.80
10	7.90	8.00	8.09	8.19	8.29	8.39	8.48	8.58	8.68	8.77
11	8.87	8.97	9.07	9.16	9.26	9.36	9.46	9.56	9.65	9.75
12	9.85	9.94	10.04	10.14	10.24	10.34	10.44	10.53	10.63	10.73

CURVE 84

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.05	0.08	0.11
1	0.15	0.20	0.25	0.30	0.35	0.41	0.48	0.54	0.61	0.68
2	0.74	0.82	0.89	0.97	1.04	1.12	1.20	1.28	1.36	1.44
3	1.52	1.60	1.68	1.77	1.85	1.94	2.03	2.11	2.20	2.29
4	2.37	2.46	2.55	2.64	2.73	2.82	2.91	3.00	3.09	3.18
5	3.27	3.37	3.46	3.55	3.64	3.73	3.82	3.92	4.01	4.11
6	4.20	4.29	439	4.48	4.58	4.67	4.76	4.86	4.95	5.05
7	5.14	5.24	5.33	5.43	5.52	5.62	5.71	5.81	5.91	6.00
8	6.10	6.20	6.30	6.39	6.48	6.58	6.68	6.77	6.87	6.97
9	7.06	7.16	7.26	7.35	7.45	7.55	7.65	7.74	7.84	7.94
10	8.03	8.13	8.23	8.33	8.42	8.52	8.61	8.71	8.81	8.91
11	9.01	9.10	9.20	9.30	9.40	9.50	9.60	9.69	9.79	9.89
12	9.99	10.09	10.19	10.28	10.38	10.48	10.57	10.67	10.77	10.87

CURVE 85

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.06	0.09	0.13
1	0.18	0.22	0.28	0.33	0.39	0.45	0.52	0.59	0.65	0.73
2	0.80	0.87	0.95	1.02	1.10	1.18	1.26	1.34	1.42	1.51
3	1.59	1.68	1.76	1.85	1.93	2.02	2.11	2.20	2.28	2.37
4	2.46	2.55	2.64	2.73	2.82	2.91	3.00	3.09	3.19	3.28
5	3.37	3.47	3.56	3.65	3.74	3.84	3.93	4.03	4.12	4.21
6	4.31	4.40	4.50	4.59	5.69	4.78	4.87	4.97	5.06	5.16
7	5.26	5.35	5.45	5.55	5.64	5.74	5.84	5.93	6.03	6.12
8	6.22	6.32	6.41	6.50	6.60	6.70	6.80	6.90	6.99	7.09
9	7.19	7.28	7.38	7.48	7.57	7.67	7.77	7.87	7.97	8.06
10	8.16	8.26	8.35	8.45	8.55	8.65	8.75	8.84	8.94	9.04
11	9.14	9.24	9.33	9.43	9.53	9.63	9.73	9.82	9.92	10.02
12	10.12	10.22	10.32	10.42	10.51	10.61	10.71	10.81	10.91	11.01

Exhibit 2-7A

RAINFALL-RUNOFF DEPTHS FOR SELECTED RUNOFF CURVE NUMBERS

CURVE 80

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.05
1	0.08	0.11	0.15	0.19	0.24	0.29	0.34	0.39	0.44	0.50
2	0.56	0.62	0.68	0.75	0.82	0.89	0.96	1.03	1.10	1.17
3	1.25	1.33	1.40	1.48	1.56	1.64	1.72	1.80	1.88	1.96
4	2.04	2.12	2.20	2.29	2.38	2.46	2.55	2.63	2.72	2.81
5	2.89	2.98	3.07	3.16	3.25	3.34	3.43	3.52	3.61	3.69
6	3.78	3.87	3.96	4.05	4.14	4.23	4.32	4.42	4.51	4.60
7	4.69	4.79	4.88	4.97	5.06	5.16	5.25	5.34	5.44	5.53
8	5.62	5.72	5.81	5.91	6.00	6.09	6.19	6.28	6.38	6.47
9	6.57	6.66	6.76	6.85	6.95	7.04	7.14	7.23	7.33	7.43
10	7.52	7.62	7.71	7.81	7.90	8.00	8.10	8.19	8.29	8.38
11	8.48	8.58	8.67	8.77	8.87	8.97	9.06	9.16	9.26	9.35
12	9.45	9.55	9.65	9.75	9.84	9.94	10.04	10.14	10.24	10.33

CURVE 81

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.04	0.07
1	0.10	0.13	0.17	0.21	0.26	0.31	0.36	0.42	0.48	0.54
2	0.60	0.66	0.73	0.80	0.87	[illegible]	1.01	1.09	1.16	1.23
3	1.31	1.39	1.47	1.55	1.63	1.71	1.79	1.87	1.95	2.03
4	2.12	[illegible]	2.29	2.37	[illegible]	2.55	2.63	2.72	2.81	2.89
5	2.98	3.07	3.16	3.25	3.34	3.43	3.52	3.61	3.70	[illegible]
6	3.88	3.97	4.06	4.16	4.25	4.34	4.43	4.52	4.61	4.71
7	[illegible]	[illegible]	4.99	5.08	5.17	5.27	5.36	5.46	5.55	5.64
8	[illegible]	[illegible]	5.93	6.02	6.11	6.20	6.29	6.39	6.49	6.59
9	6.69	6.79	6.88	6.97	7.06	7.15	7.25	7.35	7.45	7.55
10	7.64	7.74	7.84	7.93	8.03	8.12	8.21	8.31	8.41	8.51
11	[illegible]	[illegible]	8.79	8.88	8.98	9.08	9.18	9.28	9.38	9.48
12	9.58	[illegible]	9.77	9.86	9.95	10.05	10.15	10.25	10.35	10.45

CURVE 82

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.05	0.08
1	0.11	0.15	0.19	0.24	0.29	0.34	0.40	0.46	0.52	0.58
2	0.65	0.72	0.78	0.85	0.92	0.99	1.06	1.14	1.22	1.30
3	1.38	1.46	1.53	1.61	1.69	1.77	1.86	1.94	2.02	2.11
4	[illegible]	[illegible]	[illegible]	2.46	2.55	2.64	2.73	2.81	2.90	2.99
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3.80	[illegible]
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.63	4.73	4.82
7	4.92	[illegible]	[illegible]	[illegible]	5.29	[illegible]	5.48	[illegible]	5.67	5.76
8	[illegible]	[illegible]	6.05	6.14	6.24	6.33	6.43	6.53	6.62	6.71
9	6.81	6.91	7.01	7.11	7.21	7.30	7.40	7.49	7.59	7.68
10	7.77	[illegible]	7.97	8.07	8.17	8.26	8.36	8.46	8.55	8.64
11	8.74	8.84	8.94	9.04	9.14	9.23	9.33	9.42	9.52	9.61
12	9.71	9.81	9.90	10.00	10.10	10.20	10.29	10.39	10.49	10.59

Exhibit 2-7A

RAINFALL-RUNOFF DEPTHS FOR SELECTED RUNOFF CURVE NUMBERS

CURVE 77

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03
1	0.05	0.07	0.10	0.14	0.18	0.22	0.26	0.30	0.34	0.39
2	0.45	0.50	0.56	0.62	0.68	0.74	0.80	0.86	0.93	1.00
2yr 3	1.07	1.14	1.21	1.28	1.35	1.43	1.50	1.57	1.65	1.73
5yr 4	1.81	1.89	1.97	2.05	2.13	2.21	2.29	2.37	2.45	2.53
10yr 5	2.62	2.70	2.79	2.87	2.96	3.04	3.13	3.22	3.30	3.39
50yr 6	3.48	3.56	3.65	3.74	3.83	3.92	4.00	4.09	4.18	4.27
100yr 7	4.36	4.45	4.54	4.63	4.72	4.81	4.90	5.00	5.09	5.18
8	5.27	5.36	5.45	5.55	5.64	5.73	5.82	5.92	6.01	6.10
9	6.19	6.29	6.38	6.47	6.57	6.66	6.76	6.85	6.94	7.04
10	7.13	7.23	7.32	7.42	7.51	7.60	7.70	7.79	7.89	7.98
11	8.08	8.18	8.27	8.37	8.46	8.55	8.65	8.75	8.84	8.94
12	9.03	9.13	9.23	9.32	9.42	9.51	9.61	9.71	9.81	9.90

CURVE 78

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03
1	0.06	0.09	0.12	0.15	0.19	0.23	0.27	0.32	0.37	0.42
2	0.48	0.54	0.60	0.66	0.72	0.79	0.86	0.93	0.99	1.06
3	1.13	1.20	1.27	1.35	1.43	1.50	1.58	1.65	1.73	1.81
4	1.89	1.97	2.05	2.13	2.22	2.30	2.38	2.46	2.54	2.63
5	2.72	2.81	2.89	2.98	3.06	3.15	3.24	3.32	3.41	3.50
6	3.59	3.67	3.76	3.85	3.94	4.03	4.12	4.22	4.31	4.39
7	4.48	4.58	4.67	4.76	4.85	4.94	5.03	5.12	5.22	5.31
8	5.40	5.49	5.58	5.67	5.77	5.86	5.95	6.05	6.14	6.24
9	6.33	6.43	6.52	6.61	6.71	6.80	6.90	6.99	7.09	7.18
10	7.27	7.37	7.46	7.56	7.65	7.75	7.84	7.94	8.04	8.13
11	8.23	8.33	8.42	8.52	8.61	8.71	8.80	8.90	8.99	9.09
12	9.19	9.28	9.37	9.47	9.56	9.66	9.76	9.86	9.95	10.05

CURVE 79

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.05
1	0.07	0.10	0.13	0.17	0.21	0.26	0.31	0.36	0.41	0.46
2	0.52	0.58	0.64	0.70	0.77	0.84	0.91	0.98	1.05	1.12
3	1.19	1.26	1.34	1.42	1.49	1.56	1.64	1.72	1.80	1.88
4	1.96	2.04	2.13	2.21	2.29	2.38	2.46	2.55	2.63	2.72
5	2.80	2.89	2.98	3.07	3.15	3.24	3.32	3.41	3.50	3.59
6	3.68	3.77	3.86	3.95	4.04	4.13	4.22	4.31	4.40	4.49
7	4.58	4.68	4.77	4.86	4.95	5.04	5.13	5.23	5.32	5.42
8	5.51	5.60	5.68	5.78	5.88	5.98	6.07	6.16	6.26	6.35
9	6.45	6.54	6.63	6.73	6.82	6.92	7.01	7.11	7.20	7.30
10	7.39	7.49	7.58	7.68	7.77	7.87	7.97	8.06	8.16	8.25
11	8.35	8.44	8.54	8.64	8.74	8.83	8.92	9.02	9.12	9.22
12	9.31	9.40	9.50	9.60	9.70	9.79	9.89	9.98	10.08	10.18

Exhibit 2-7A

RAINFALL-RUNOFF DEPTHS FOR SELECTED RUNOFF CURVE NUMBERS

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0									0	0.01
1	0.02	0.04	0.06	0.09	0.12	0.15	0.18	0.21	0.27	0.31
2	0.35	0.40	0.45	0.50	0.55	0.61	0.67	0.73	0.79	0.85
2yr 3	0.91	0.97	1.04	1.11	1.18	1.25	1.32	1.38	1.45	1.52
5yr 4	1.60	1.68	1.75	1.83	1.90	1.98	2.06	2.13	2.21	2.29
10yr 5	2.37	2.45	2.53	2.61	2.69	2.78	2.86	2.94	3.02	3.10
50yr 6	3.19	3.28	3.36	3.45	3.53	3.62	3.70	3.79	3.88	3.96
100yr 7	4.05	4.14	4.23	4.31	4.39	4.48	4.57	4.66	4.75	4.84
8	4.93	5.02	5.11	5.20	5.29	5.38	5.47	5.56	5.65	5.75
9	5.84	5.93	6.02	6.11	6.20	6.29	6.38	6.47	6.56	6.65
10	6.75	6.84	6.94	7.03	7.12	7.21	7.30	7.40	7.50	7.60
11	7.69	7.79	7.88	7.98	8.07	8.16	8.25	8.35	8.44	8.54
12	8.63	8.73	8.82	8.91	9.00	9.10	9.20	9.30	9.40	9.49

CURVE 74

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
1	0.03	0.05	0.07	0.10	0.13	0.16	0.20	0.24	0.28	0.33
2	0.38	0.43	0.48	0.53	0.59	0.65	0.71	0.77	0.83	0.89
3	0.95	1.02	1.09	1.16	1.23	1.30	1.37	1.44	1.52	1.59
4	1.67	1.74	1.82	1.89	1.97	2.04	2.12	2.20	2.28	2.36
5	2.44	2.52	2.61	2.69	2.77	2.85	2.94	3.02	3.11	3.19
6	3.27	3.36	3.45	3.53	3.62	3.71	3.79	3.88	3.97	4.06
7	4.15	4.24	4.32	4.40	4.49	4.58	4.67	4.76	4.86	4.95
8	5.04	5.13	5.22	5.31	5.40	5.49	5.58	5.67	5.76	5.85
9	5.94	6.04	6.13	6.22	6.32	6.41	6.50	6.59	6.68	6.78
10	6.87	6.96	7.05	7.15	7.24	7.34	7.43	7.53	7.63	7.73
11	[illegible]	7.91	8.00	8.10	8.19	8.29	8.38	8.47	8.56	8.66
12	8.76	[illegible]	8.95	[illegible]	[illegible]	9.23	9.32	9.42	9.51	9.61

CURVE 75

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	[illegible]	[illegible]	[illegible]	0.00	0.00	0.00	0.00	0.00	0.01	0.02
1	[illegible]	[illegible]	[illegible]	0.11	0.15	0.19	0.23	0.27	0.31	0.36
2	0.41	0.46	[illegible]	[illegible]	0.63	0.69	0.75	0.81	0.88	0.95
3	1.01	1.08	1.15	1.22	1.29	1.36	1.43	1.51	1.58	1.66
4	1.74	1.81	1.89	1.97	2.05	2.13	2.21	2.29	2.37	2.46
5	2.54	2.62	2.70	2.78	2.87	2.95	3.04	3.12	3.21	3.29
6	3.38	3.47	3.55	3.64	3.73	3.81	3.90	3.99	4.08	4.17
7	4.26	4.35	4.44	4.53	4.62	4.71	4.80	4.89	4.98	5.07
8	5.16	5.25	5.34	5.43	5.52	5.61	5.70	5.80	5.89	5.98
9	6.07	6.17	6.26	6.35	6.45	6.54	6.63	6.73	6.82	6.91
10	7.01	7.10	7.19	7.28	7.37	7.47	7.57	7.66	7.75	7.85
11	7.94	8.04	8.14	8.23	8.33	8.42	8.51	8.61	8.71	8.80
12	8.90	8.99	9.08	9.18	9.28	9.37	9.47	9.56	9.66	9.76

CURVE 76

Exhibit 2-7A

RAINFALL-RUNOFF DEPTHS FOR SELECTED RUNOFF CURVE NUMBERS

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0								0.00	0.00	0.00
1	0.01	0.02	0.03	0.05	0.07	0.10	0.13	0.16	0.19	0.22
2	0.26	0.30	0.34	0.39	0.44	0.49	0.54	0.59	0.64	0.70
3	0.76	0.82	0.88	0.94	1.00	1.06	1.13	1.19	1.26	1.33
4	1.39	1.46	1.53	1.60	1.67	1.74	1.81	1.89	1.97	2.04
5	2.11	2.19	2.27	2.34	2.42	2.50	2.58	2.66	2.74	2.82
6	2.90	2.98	3.06	3.14	3.22	3.30	3.38	3.47	3.55	3.63
7	3.72	3.80	3.88	3.97	4.06	4.14	4.23	4.32	4.40	4.49
8	4.58	4.67	4.75	4.82	4.93	5.02	5.10	5.19	5.28	5.37
9	5.46	5.55	5.64	5.73	5.82	5.90	5.99	6.08	6.17	6.27
10	6.36	6.45	6.54	6.63	6.72	6.81	6.90	6.99	7.08	7.18
11	7.27	7.36	7.45	7.54	7.63	7.73	7.82	7.91	8.01	8.10
12	8.19	8.28	8.38	8.47	8.56	8.65	8.75	8.84	8.94	9.03

CURVE 71

Inches	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
1	0.01	0.02	0.04	0.06	0.08	0.11	0.14	0.17	0.21	0.25
2	0.29	0.33	0.38	0.43	0.48	0.53	0.58	0.63	0.69	0.75
3	0.81	0.87	0.93	0.99	1.05	1.12	1.19	1.26	1.32	1.39
4	1.46	1.53	1.60	1.68	1.75	1.82	1.89	1.97	2.05	2.12
5	2.19	2.27	2.35	2.43	2.51	2.59	2.67	2.75	2.83	2.91
6	2.99	3.08	3.16	3.24	3.32	3.41	3.49	3.57	3.66	3.75
7	3.83	3.91	4.00	4.08	4.17	4.26	4.35	4.44	4.52	4.61
8	4.69	4.78	4.87	4.96	5.05	5.14	5.23	5.31	5.40	5.49
9	5.58	5.67	5.76	5.85	5.94	6.03	6.13	6.22	6.31	6.40
10	6.49	6.58	6.67	6.76	6.85	6.95	7.04	7.13	7.22	7.31
11	7.40	7.50	7.59	7.69	7.78	7.87	7.96	8.05	8.15	8.25
12	8.34	8.43	8.52	8.62	8.71	8.81	8.90	8.99	9.09	9.18

CURVE 72

Inches	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
1	0.02	0.03	0.05	0.07	0.10	0.13	0.16	0.20	0.24	0.28
2	0.32	0.37	0.41	0.46	0.52	0.57	0.62	0.68	0.74	0.80
3	0.86	0.92	0.98	1.04	1.11	1.18	1.25	1.32	1.39	1.46
4	1.53	1.60	1.67	1.75	1.82	1.90	1.97	2.04	2.12	2.20
5	2.28	2.36	2.44	2.52	2.60	2.68	2.76	2.84	2.92	3.00
6	3.09	3.17	3.25	3.34	3.43	3.51	3.60	3.68	3.76	3.85
7	3.94	4.02	4.11	4.20	4.29	4.37	4.46	4.55	4.64	4.73
8	4.81	4.90	4.99	5.08	5.17	5.26	5.35	5.44	5.53	5.62
9	5.71	5.80	5.89	5.98	6.07	6.16	6.25	6.35	6.44	6.53
10	6.62	6.71	6.81	6.90	6.99	7.08	7.17	7.27	7.36	7.45
11	7.54	7.64	7.73	7.82	7.92	8.01	8.10	8.20	8.29	8.38
12	8.48	8.57	8.67	8.76	8.86	8.95	9.05	9.14	9.23	9.33

CURVE 73

Exhibit 2-7A

RAINFALL-RUNOFF DEPTHS FOR SELECTED RUNOFF CURVE NUMBERS

CURVE 68

	Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
	0										
	1	0.00	0.01	0.01	0.02	0.04	0.06	0.08	0.11	0.13	0.16
	2	0.19	0.23	0.26	0.30	0.34	0.38	0.43	0.48	0.53	0.58
2	3	0.63	0.68	0.73	0.78	0.84	0.90	0.96	1.02	1.08	1.14
5	4	1.20	1.26	1.33	1.40	1.47	1.53	1.60	1.67	1.74	1.81
10	5	1.88	1.95	2.02	2.09	2.16	2.24	2.32	2.39	2.47	2.54
50	6	2.62	2.70	2.78	2.85	2.93	3.01	3.09	3.17	3.25	3.33
100	7	3.41	3.49	3.57	3.65	3.73	3.82	3.90	3.99	4.07	4.15
	8	4.23	4.32	4.40	4.49	4.57	4.66	4.74	4.83	4.91	5.00
	9	5.09	5.17	5.26	5.35	5.43	5.52	5.61	5.70	5.78	5.87
	10	5.96	6.05	6.14	6.23	6.32	6.40	6.49	6.58	6.67	6.76
	11	6.85	6.94	7.03	7.12	7.21	7.30	7.39	7.48	7.57	7.66
	12	7.76	7.84	7.94	8.03	8.12	8.21	8.31	8.40	8.49	8.58

CURVE 69

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
1	0.00	0.01	0.02	0.03	0.05	0.07	0.09	0.12	0.15	0.18
2	0.22	0.25	0.29	0.33	0.38	0.42	0.47	0.52	0.57	0.62
3	0.67	0.72	0.78	0.84	0.90	0.96	1.02	1.08	1.14	1.20
4	1.27	1.33	1.40	1.47	1.53	1.60	1.67	1.74	1.81	1.88
5	1.96	2.03	2.10	2.18	2.25	2.33	2.40	2.48	2.56	2.63
6	2.71	2.79	2.87	2.95	3.03	3.11	3.19	3.27	3.35	3.43
7	3.51	3.60	3.68	3.76	3.84	3.93	4.01	4.10	4.18	4.26
8	4.35	4.44	4.52	4.61	4.69	4.78	4.86	4.95	5.04	5.12
9	5.21	5.30	5.39	5.48	5.56	5.65	5.74	5.82	5.91	6.00
10	6.09	6.18	6.27	6.36	6.45	6.54	6.63	6.72	6.81	6.90
11	6.99	7.08	7.17	7.27	7.36	7.45	7.54	7.63	7.72	7.81
12	7.90	7.99	8.09	8.18	8.27	8.37	8.46	8.55	8.64	8.73

CURVE 70

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
1	0.00	0.01	0.02	0.04	0.06	0.08	0.11	0.14	0.17	0.20
2	0.24	0.28	0.32	0.36	0.40	0.45	0.50	0.55	0.60	0.65
3	0.71	0.77	0.83	0.89	0.95	1.01	1.07	1.13	1.19	1.25
4	1.33	1.40	1.46	1.53	1.60	1.67	1.74	1.81	1.88	1.96
5	2.04	2.11	2.19	2.26	2.33	2.41	2.49	2.57	2.64	2.72
6	2.80	2.88	2.96	3.04	3.13	3.21	3.29	3.37	3.45	3.53
7	3.61	3.70	3.79	3.87	3.95	4.04	4.12	4.20	4.28	4.37
8	4.46	4.55	4.64	4.72	4.81	4.90	4.98	5.07	5.16	5.25
9	5.33	5.42	5.51	5.60	5.69	5.78	5.87	5.96	6.05	6.14
10	6.23	6.32	6.41	6.50	6.59	6.68	6.77	6.86	6.95	7.04
11	7.13	7.22	7.31	7.40	7.49	7.58	7.68	7.77	7.86	7.96
12	8.05	8.14	8.23	8.33	8.42	8.51	8.60	8.70	8.79	8.88

Exhibit 2-7A

RAINFALL-RUNOFF DEPTHS FOR SELECTED RUNOFF CURVE NUMBERS

CURVE 65

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0										
1	0.00	0.00	0.00	0.01	0.02	0.03	0.04	0.06	0.08	0.10
2	0.13	0.16	0.19	0.23	0.26	0.30	0.33	0.37	0.42	0.46
3	0.50	0.55	0.60	0.65	0.70	0.75	0.80	0.86	0.91	0.97
4	1.03	1.09	1.15	1.21	1.27	1.33	1.39	1.45	1.52	1.58
5	1.65	1.72	1.78	1.85	1.92	1.99	2.06	2.13	2.20	2.28
6	2.35	2.42	2.50	2.57	2.64	2.72	2.80	2.87	2.94	3.02
7	3.10	3.18	3.25	3.33	3.41	3.49	3.57	3.64	3.73	3.81
8	3.89	3.97	4.05	4.13	4.22	4.30	4.38	4.46	4.54	4.62
9	4.71	4.80	4.88	4.96	5.05	5.13	5.22	5.30	5.39	5.47
10	5.56	5.65	5.73	5.82	5.90	5.99	6.08	6.17	6.26	6.34
11	6.43	6.52	6.60	6.69	6.78	6.87	6.96	7.05	7.14	7.23
12	7.31	7.40	7.49	7.58	7.67	7.76	7.85	7.94	8.03	8.12

CURVE 66

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
1	0.00	0.00	0.01	0.01	0.02	0.04	0.06	0.08	0.10	0.12
2	0.15	0.18	0.21	0.25	0.29	0.33	0.37	0.41	0.45	0.50
3	0.55	0.60	0.65	0.60	0.75	0.80	0.86	0.91	0.97	1.03
4	1.09	1.15	1.21	1.27	1.33	1.39	1.46	1.53	1.59	1.66
5	1.73	1.80	1.87	1.94	2.01	2.08	2.15	2.22	2.29	2.36
6	2.44	2.51	2.59	2.67	2.74	2.82	2.89	2.97	3.05	3.12
7	3.20	3.28	3.36	3.44	3.52	3.60	3.68	3.76	3.84	3.93
8	4.01	4.09	4.17	4.26	4.34	4.43	4.51	4.59	4.67	4.76
9	4.84	4.93	5.01	5.10	5.18	5.27	5.35	5.43	5.50	5.61
10	5.70	5.78	5.87	5.96	6.05	6.13	6.22	6.31	6.40	6.49
11	6.57	6.66	6.75	6.84	6.93	7.02	7.11	7.20	7.29	7.38
12	7.46	7.55	7.64	7.73	7.82	7.92	8.01	8.10	8.19	8.28

CURVE 67

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
1	0.00	0.00	0.01	0.02	0.03	0.05	0.07	0.09	0.12	0.15
2	0.18	0.21	0.24	0.28	0.32	0.36	0.40	0.44	0.49	0.54
3	0.59	0.64	0.69	0.74	0.79	0.85	0.91	0.97	1.03	1.09
4	1.15	1.21	1.27	1.34	1.40	1.47	1.53	1.60	1.67	1.74
5	1.81	1.88	1.95	2.02	2.09	2.16	2.23	2.31	2.39	2.46
6	2.54	2.61	2.69	2.76	2.84	2.92	3.00	3.08	3.15	3.23
7	3.31	3.39	3.47	3.55	3.64	3.72	3.80	3.88	3.96	4.04
8	4.13	4.21	4.29	4.38	4.46	4.55	4.63	4.71	4.80	4.89
9	4.97	5.06	5.14	5.23	5.31	5.40	5.49	5.58	5.66	5.75
10	5.84	5.92	6.01	6.10	6.19	6.28	6.36	6.45	6.54	6.63
11	6.72	6.81	6.90	6.99	7.08	7.17	7.26	7.35	7.44	7.53
12	7.62	7.71	7.80	7.89	7.98	8.07	8.16	8.25	8.35	8.44

Exhibit 2-7A

RAINFALL-RUNOFF DEPTHS FOR SELECTED RUNOFF CURVE NUMBERS

CURVE 62

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0										
1						0.01	0.02	0.03	0.05	0.07
2	0.09	0.11	0.13	0.16	0.19	0.22	0.25	0.28	0.32	0.36
3	0.40	0.44	0.48	0.52	0.56	0.61	0.66	0.71	0.76	0.81
4	0.86	0.91	0.96	1.02	1.08	1.14	1.20	1.26	1.32	1.38
5	1.44	1.50	1.56	1.62	1.68	1.74	1.81	1.88	1.95	2.02
6	2.09	2.16	2.23	2.30	2.37	2.44	2.51	2.58	2.65	2.72
7	2.80	2.87	2.94	3.02	3.09	3.17	3.24	3.32	3.40	3.48
8	3.55	3.63	3.71	3.79	3.86	3.94	4.02	4.10	4.18	4.26
9	4.34	4.42	4.50	4.59	4.67	4.75	4.83	4.91	5.00	5.08
10	5.16	5.25	5.33	5.41	5.50	5.58	5.66	5.75	5.83	5.92
11	6.00	6.09	6.17	6.26	6.34	6.43	6.52	6.60	6.69	6.77
12	6.86	6.95	7.04	7.13	7.21	7.30	7.39	7.48	7.56	7.65

CURVE 63

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
1						0.02	0.03	0.04	0.06	0.08
2	0.10	0.12	0.15	0.18	0.21	0.25	0.28	0.32	0.35	0.39
3	0.43	0.47	0.52	0.57	0.61	0.66	0.71	0.76	0.81	0.86
4	0.92	0.98	1.03	1.09	1.15	1.21	1.26	1.32	1.38	1.44
5	1.51	1.58	1.64	1.70	1.76	1.83	1.90	1.97	2.04	2.11
6	2.18	2.25	2.32	2.39	2.47	2.54	2.61	2.68	2.76	2.83
7	2.91	2.98	3.06	3.13	3.21	3.28	3.36	3.44	3.52	3.59
8	3.67	3.75	3.83	3.91	3.99	4.07	4.15	4.23	4.31	4.39
9	4.48	4.56	4.64	4.72	4.80	4.89	4.97	5.05	5.14	5.22
10	5.30	5.39	5.47	5.56	5.64	5.73	5.81	5.90	5.98	6.07
11	6.15	6.24	6.33	6.41	6.50	6.59	6.68	6.76	6.84	6.93
12	7.02	7.11	7.20	7.29	7.38	7.47	7.55	7.64	7.73	7.82

CURVE 64

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
1	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.05	0.07	0.09
2	0.11	0.14	0.17	0.20	0.23	0.26	0.30	0.34	0.38	0.42
3	0.47	0.51	0.56	0.60	0.65	0.70	0.75	0.80	0.85	0.91
4	0.97	1.03	1.09	1.15	1.21	1.26	1.32	1.38	1.45	1.51
5	1.58	1.64	1.71	1.77	1.84	1.91	1.98	2.05	2.12	2.19
6	2.26	2.33	2.40	2.48	2.55	2.62	2.70	2.77	2.85	2.92
7	3.00	3.07	3.15	3.23	3.30	3.38	3.46	3.54	3.62	3.69
8	3.77	3.85	3.93	4.01	4.09	4.18	4.26	4.34	4.42	4.50
9	4.59	4.67	4.75	4.84	4.92	5.00	5.09	5.17	5.26	5.34
10	5.43	5.51	5.59	5.68	5.76	5.85	5.94	6.02	6.11	6.20
11	6.28	6.37	6.46	6.55	6.64	6.72	6.81	6.90	6.99	7.07
12	7.16	7.25	7.34	7.43	7.52	7.61	7.70	7.78	7.87	7.96

Exhibit 2-7A

RAINFALL-RUNOFF DEPTHS FOR SELECTED RUNOFF CURVE NUMBERS

These tables may be used in lieu of Exhibit 2-7. They have been prepared to eliminate the need for interpolation which is often necessary with the use of Exhibit 2-7.

Inches of runoff associated with inches of precipitation for various curve numbers as shown in these tables are based on the runoff equation at bottom of page 2-5.

If inches of runoff are needed for precipitation amounts greater than 12", refer to Technical Release No. 16.

2yr.
5yr.
10yr.
50yr.
100yr.

CURVE 60

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0										
1	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.04
2	0.06	0.08	0.10	0.12	0.14	0.17	0.20	0.23	0.27	0.30
3	0.33	0.37	0.41	0.45	0.49	0.53	0.57	0.62	0.67	0.72
4	0.76	0.81	0.86	0.91	0.97	1.03	1.08	1.13	1.19	1.25
5	1.30	1.36	1.42	1.48	1.54	1.61	1.67	1.73	1.80	1.86
6	1.92	1.99	2.06	2.12	2.19	2.26	2.33	2.40	2.47	2.54
7	2.61	2.68	2.75	2.82	2.89	2.97	3.04	3.11	3.18	3.26
8	3.34	3.41	3.49	3.56	3.64	3.72	3.79	3.87	3.95	4.03
9	4.10	4.18	4.26	4.34	4.42	4.50	4.58	4.66	4.74	4.82
10	4.90	4.98	5.07	5.15	5.23	5.31	5.39	5.48	5.56	5.64
11	5.73	5.81	5.89	5.98	6.06	6.14	6.22	6.31	6.40	6.48
12	6.57	6.65	6.73	6.82	6.91	6.99	7.08	7.17	7.26	7.34

CURVE 61

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
1						0.01	0.02	0.03	0.04	0.05
2	0.07	0.09	0.11	0.14	0.17	0.20	0.23	0.26	0.29	0.32
3	0.36	0.40	0.44	0.48	0.52	0.57	0.62	0.67	0.71	0.76
4	0.81	0.86	0.91	0.96	1.02	1.08	1.13	1.19	1.25	1.31
5	1.37	1.43	1.49	1.55	1.61	1.68	1.74	1.81	1.87	1.94
6	2.01	2.07	2.14	2.21	2.28	2.35	2.42	2.49	2.56	2.63
7	2.70	2.77	2.84	2.91	2.98	3.06	3.14	3.22	3.29	3.37
8	3.44	3.52	3.60	3.67	3.75	3.83	3.91	3.99	4.07	4.14
9	4.22	4.30	4.38	4.46	4.54	4.62	4.71	4.79	4.87	4.95
10	5.03	5.11	5.20	5.28	5.36	5.44	5.53	5.61	5.70	5.78
11	5.87	5.95	6.03	6.12	6.20	6.29	6.38	6.46	6.55	6.63
12	6.72	6.80	6.89	6.98	7.06	7.15	7.24	7.33	7.41	7.50

Exhibit 2-7A

CURVE 60

RUNOFF FOR INCHES OF RAINFALL

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
21	14.69	14.78	14.87	14.97	15.06	15.15	15.25	15.34	15.44	15.53
22	15.62	15.72	15.81	15.91	16.00	16.09	16.19	16.28	16.38	16.47
23	16.57	16.66	16.76	16.85	16.94	17.04	17.13	17.23	17.32	17.42
24	17.51	17.61	17.70	17.80	17.89	17.99	18.08	18.18	18.27	18.37
25	18.46	18.56	18.65	18.75	18.84	18.94	19.03	19.13	19.22	19.32
26	19.42	19.51	19.61	19.70	19.80	19.89	19.99	20.08	20.18	20.28
27	20.37	20.47	20.56	20.66	20.76	20.85	20.95	21.04	21.14	21.23
28	21.33	21.43	21.52	21.62	21.71	21.81	21.91	22.00	22.10	22.20
29	22.29	22.39	22.48	22.58	22.68	22.77	22.87	22.97	23.06	23.16
30	23.26	23.35	23.45	23.54	23.64	23.74	23.83	23.93	24.03	24.12
31	24.22	24.32	24.41	24.51	24.61	24.70	24.80	24.90	24.99	25.09
32	25.19	25.28	25.38	25.48	25.57	25.67	25.77	25.87	25.96	26.06
33	26.16	26.25	26.35	26.45	26.54	26.64	26.74	26.84	26.93	27.03
34	27.13	27.22	27.32	27.42	27.52	27.61	27.71	27.81	27.90	28.00
35	28.10	28.20	28.29	28.39	28.49	28.59	28.68	28.78	28.88	28.97
36	29.07	29.17	29.27	29.36	29.46	29.56	29.66	29.75	29.85	29.95
37	30.05	30.14	30.24	30.34	30.44	30.53	30.63	30.73	30.83	30.92
38	31.02	31.12	31.22	31.32	31.41	31.51	31.61	31.71	31.80	31.90
39	32.00	32.10	32.19	32.29	32.39	32.49	32.59	32.68	32.78	32.88
40	32.98	33.08	33.17	33.27	33.37	33.47	33.56	33.66	33.76	33.86

NOTE: Runoff value determined by equation $Q = \frac{(P-0.2\,S)^2}{P+0.8\,S}$

REFERENCE: National Engineering Handbook, Section 4, HYDROLOGY

CURVE
60

RUNOFF FOR INCHES OF RAINFALL

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0										
1					0.00	0.00	0.01	0.02	0.03	0.04
2	0.06	0.08	0.10	0.12	0.15	0.17	0.20	0.23	0.26	0.30
3	0.33	0.37	0.41	0.45	0.49	0.53	0.57	0.62	0.67	0.71
4	0.76	0.81	0.86	0.91	0.97	1.02	1.07	1.13	1.19	1.24
5	1.30	1.36	1.42	1.48	1.54	1.60	1.66	1.73	1.79	1.86
6	1.92	1.99	2.05	2.12	2.19	2.25	2.32	2.39	2.46	2.53
7	2.60	2.67	2.74	2.82	2.89	2.96	3.04	3.11	3.18	3.26
8	3.33	3.41	3.48	3.56	3.63	3.71	3.79	3.87	3.94	4.02
9	4.10	4.18	4.26	4.34	4.42	4.49	4.57	4.65	4.74	4.82
10	4.90	4.98	5.06	5.14	5.22	5.31	5.39	5.47	5.55	5.64
11	5.72	5.80	5.89	5.97	6.05	6.14	6.22	6.31	6.39	6.48
12	6.56	6.65	6.73	6.82	6.90	6.99	7.08	7.16	7.25	7.34
13	7.42	7.51	7.60	7.68	7.77	7.86	7.95	8.03	8.12	8.21
14	8.30	8.38	8.47	8.56	8.65	8.74	8.83	8.92	9.01	9.09
15	9.18	9.27	9.36	9.45	9.54	9.63	9.72	9.81	9.90	9.99
16	10.08	10.17	10.26	10.35	10.44	10.53	10.62	10.71	10.81	10.90
17	10.99	11.08	11.17	11.26	11.35	11.44	11.54	11.63	11.72	11.81
18	11.90	11.99	12.09	12.18	12.27	12.36	12.45	12.55	12.64	12.73
19	12.82	12.92	13.01	13.10	13.19	13.29	13.38	13.47	13.57	13.66
20	13.75	13.85	13.94	14.03	14.12	14.22	14.31	14.40	14.50	14.59

NOTE: Runoff value determined by equation $Q = \frac{(P-0.2\,S)^2}{P+0.8\,S}$

REFERENCE: National Engineering Handbook, Section 4, HYDROLOGY

CURVE
59

RUNOFF FOR INCHES OF RAINFALL

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
21	14.48	14.57	14.67	14.76	14.85	14.95	15.04	15.13	15.23	15.32
22	15.41	15.51	15.60	15.69	15.79	15.88	15.98	16.07	16.16	16.26
23	16.35	16.45	16.54	16.63	16.73	16.82	16.92	17.01	17.11	17.20
24	17.29	17.39	17.48	17.58	17.67	17.77	17.86	17.96	18.05	18.15
25	18.24	18.34	18.43	18.53	18.62	18.72	18.81	18.91	19.00	19.10
26	19.19	19.29	19.38	19.48	19.57	19.67	19.76	19.86	19.95	20.05
27	20.14	20.24	20.33	20.43	20.53	20.62	20.72	20.81	20.91	21.00
28	21.10	21.19	21.29	21.39	21.48	21.58	21.67	21.77	21.87	21.96
29	22.06	22.15	22.25	22.35	22.44	22.54	22.63	22.73	22.83	22.92
30	23.02	23.11	23.21	23.31	23.40	23.50	23.60	23.69	23.79	23.88
31	23.98	24.08	24.17	24.27	24.37	24.46	24.56	24.66	24.75	24.85
32	24.95	25.04	25.14	25.24	25.33	25.43	25.53	25.62	25.72	25.82
33	25.91	26.01	26.11	26.20	26.30	26.40	26.49	26.59	26.69	26.78
34	26.88	26.98	27.07	27.17	27.27	27.37	27.46	27.56	27.66	27.75
35	27.85	27.95	28.05	28.14	28.24	28.34	28.43	28.53	28.63	28.73
36	28.82	28.92	29.02	29.11	29.21	29.31	29.41	29.50	29.60	29.70
37	29.79	29.89	29.99	30.09	30.18	30.28	30.38	30.48	30.57	30.67
38	30.77	30.87	30.96	31.06	31.16	31.26	31.35	31.45	31.55	31.65
39	31.74	31.84	31.94	32.04	32.13	32.23	32.33	32.43	32.52	32.62
40	32.72	32.82	32.92	33.01	33.11	33.21	33.31	33.40	33.50	33.60

NOTE: Runoff value determined by equation $Q = \dfrac{(P-0.2\,S)^2}{P+0.8\,S}$

REFERENCE: National Engineering Handbook, Section 4, HYDROLOGY

CURVE
59

RUNOFF FOR INCHES OF RAINFALL

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0										
1					0.00	0.00	0.01	0.01	0.02	0.03
2	0.05	0.07	0.08	0.11	0.13	0.15	0.18	0.21	0.24	0.27
3	0.30	0.34	0.37	0.41	0.45	0.49	0.53	0.58	0.62	0.67
4	0.71	0.76	0.81	0.86	0.91	0.96	1.01	1.07	1.12	1.18
5	1.23	1.29	1.35	1.41	1.47	1.53	1.59	1.65	1.71	1.77
6	1.84	1.90	1.97	2.03	2.10	2.17	2.23	2.30	2.37	2.44
7	2.51	2.58	2.65	2.72	2.79	2.86	2.93	3.00	3.08	3.15
8	3.22	3.30	3.37	3.45	3.52	3.60	3.67	3.75	3.82	3.90
9	3.98	4.05	4.13	4.21	4.29	4.37	4.45	4.53	4.60	4.68
10	4.76	4.84	4.92	5.01	5.09	5.17	5.25	5.33	5.41	5.49
11	5.58	5.66	5.74	5.82	5.91	5.99	6.07	6.16	6.24	6.33
12	6.41	6.50	6.58	6.66	6.75	6.83	6.92	7.01	7.09	7.18
13	7.26	7.35	7.43	7.52	7.61	7.69	7.78	7.87	7.95	8.04
14	8.13	8.22	8.30	8.39	8.48	8.57	8.66	8.74	8.83	8.92
15	9.01	9.10	9.19	9.28	9.36	9.45	9.54	9.63	9.72	9.81
16	9.90	9.99	10.08	10.17	10.26	10.35	10.44	10.53	10.62	10.71
17	10.80	10.89	10.98	11.07	11.16	11.25	11.35	11.44	11.53	11.62
18	11.71	11.80	11.89	11.98	12.08	12.17	12.26	12.35	12.44	12.53
19	12.63	12.72	12.81	12.90	13.00	13.09	13.18	13.27	13.36	13.46
20	13.55	13.64	13.74	13.83	13.92	14.01	14.11	14.20	14.29	14.39

NOTE: Runoff value determined by equation $Q = \frac{(P-0.2\,S)^2}{P+0.8\,S}$

REFERENCE: National Engineering Handbook, Section 4, HYDROLOGY

CURVE

58

RUNOFF FOR INCHES OF RAINFALL

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
21	14.27	14.36	14.45	14.55	14.64	14.73	14.83	14.92	15.01	15.10
22	15.20	15.29	15.38	15.48	15.57	15.66	15.76	15.85	15.95	16.04
23	16.13	16.23	16.32	16.41	16.51	16.60	16.70	16.79	16.88	16.9
24	17.07	17.17	17.26	17.35	17.45	17.54	17.64	17.73	17.83	17.9
25	18.01	18.11	18.20	18.30	18.39	18.49	18.58	18.68	18.77	18.8
26	18.96	19.06	19.15	19.25	19.34	19.44	19.53	19.63	19.72	19.8
27	19.91	20.01	20.10	20.20	20.29	20.39	20.48	20.58	20.67	20.7
28	20.86	20.96	21.05	21.15	21.25	21.34	21.44	21.53	21.63	21.7
29	21.82	21.91	22.01	22.11	22.20	22.30	22.39	22.49	22.58	22.6
30	22.78	22.87	22.97	23.06	23.16	23.26	23.35	23.45	23.54	23.6
31	23.74	23.83	23.93	24.03	24.12	24.22	24.31	24.41	24.51	24.6
32	24.70	24.80	24.89	24.99	25.08	25.18	25.28	25.37	25.47	25.5
33	25.66	25.76	25.86	25.95	26.05	26.15	26.24	26.34	26.44	26.
34	26.63	26.73	26.82	26.92	27.02	27.11	27.21	27.31	27.40	27.
35	27.60	27.69	27.79	27.89	27.98	28.08	28.18	28.28	28.37	28.
36	28.57	28.66	28.76	28.86	28.95	29.05	29.15	29.25	29.34	29.
37	29.54	29.63	29.73	29.83	29.93	30.02	30.12	30.22	30.31	30.
38	30.51	30.61	30.70	30.80	30.90	31.00	31.09	31.19	31.29	31.
39	31.48	31.58	31.68	31.77	31.87	31.97	32.07	32.16	32.26	32.
40	32.46	32.55	32.65	32.75	32.85	32.94	33.04	33.14	33.24	33.

NOTE: Runoff value determined by equation $Q = \frac{(P-0.2S)^2}{P+0.8S}$

REFERENCE: National Engineering Handbook, Section 4, HYDROLOGY

CURVE 58

RUNOFF FOR INCHES OF RAINFALL

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0										
1						0.00	0.00	0.01	0.02	0.03
2	0.04	0.05	0.07	0.09	0.11	0.13	0.16	0.18	0.21	0.24
3	0.27	0.31	0.34	0.38	0.41	0.45	0.49	0.53	0.58	0.62
4	0.67	0.71	0.76	0.81	0.86	0.91	0.96	1.01	1.06	1.11
5	1.17	1.22	1.28	1.34	1.40	1.45	1.51	1.57	1.63	1.70
6	1.76	1.82	1.88	1.95	2.01	2.08	2.14	2.21	2.27	2.34
7	2.41	2.48	2.55	2.62	2.69	2.76	2.83	2.90	2.97	3.04
8	3.11	3.19	3.26	3.33	3.41	3.48	3.55	3.63	3.70	3.78
9	3.86	3.93	4.01	4.09	4.16	4.24	4.32	4.40	4.47	4.55
10	4.63	4.71	4.79	4.87	4.95	5.03	5.11	5.19	5.27	5.35
11	5.43	5.52	5.60	5.68	5.76	5.84	5.93	6.01	6.09	6.17
12	6.26	6.34	6.43	6.51	6.59	6.68	6.76	6.85	6.93	7.02
13	7.10	7.19	7.27	7.36	7.44	7.53	7.62	7.70	7.79	7.87
14	7.96	8.05	8.13	8.22	8.31	8.40	8.48	8.57	8.66	8.75
15	8.83	8.92	9.01	9.10	9.19	9.27	9.36	9.45	9.54	9.63
16	9.72	9.81	9.90	9.98	10.07	10.16	10.25	10.34	10.43	10.52
17	10.61	10.70	10.79	10.88	10.97	11.06	11.15	11.24	11.33	11.42
18	11.52	11.61	11.70	11.79	11.88	11.97	12.06	12.15	12.24	12.33
19	12.43	12.52	12.61	12.70	12.79	12.88	12.98	13.07	13.16	13.25
20	13.34	13.44	13.53	13.62	13.71	13.81	13.90	13.99	14.08	14.18

NOTE: Runoff value determined by equation $Q = \frac{(P-0.2\,S)^2}{P+0.8\,S}$

REFERENCE: National Engineering Handbook, Section 4, HYDROLOGY

CURVE 57

RUNOFF FOR INCHES OF RAINFALL

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
21	14.06	14.15	14.24	14.33	14.42	14.52	14.61	14.70	14.79	14.89
22	14.98	15.07	15.17	15.26	15.35	15.44	15.54	15.63	15.72	15.82
23	15.91	16.00	16.10	16.19	16.28	16.38	16.47	16.56	16.66	16.75
24	16.85	16.94	17.03	17.13	17.22	17.31	17.41	17.50	17.60	17.69
25	17.78	17.88	17.97	18.07	18.16	18.25	18.35	18.44	18.54	18.63
26	18.73	18.82	18.92	19.01	19.10	19.20	19.29	19.39	19.48	19.58
27	19.67	19.77	19.86	19.96	20.05	20.15	20.24	20.34	20.43	20.53
28	20.62	20.72	20.81	20.91	21.00	21.10	21.19	21.29	21.38	21.48
29	21.57	21.67	21.77	21.86	21.96	22.05	22.15	22.24	22.34	22.43
30	22.53	22.63	22.72	22.82	22.91	23.01	23.10	23.20	23.30	23.39
31	23.49	23.58	23.68	23.77	23.87	23.97	24.06	24.16	24.25	24.35
32	24.45	24.54	24.64	24.74	24.83	24.93	25.02	25.12	25.22	25.31
33	25.41	25.50	25.60	25.70	25.79	25.89	25.99	26.08	26.18	26.28
34	26.37	26.47	26.57	26.66	26.76	26.85	26.95	27.05	27.14	27.2
35	27.34	27.43	27.53	27.63	27.72	27.82	27.92	28.01	28.11	28.2
36	28.30	28.40	28.50	28.59	28.69	28.79	28.89	28.98	29.08	29.1
37	29.27	29.37	29.47	29.56	29.66	29.76	29.85	29.95	30.05	30.1
38	30.24	30.34	30.44	30.53	30.63	30.73	30.83	30.92	31.02	31.1
39	31.21	31.31	31.41	31.51	31.60	31.70	31.80	31.90	31.99	32.0
40	32.19	32.28	32.38	32.48	32.58	32.67	32.77	32.87	32.97	33.0

NOTE: Runoff value determined by equation $Q = \dfrac{(P-0.2\,S)^2}{P+0.8\,S}$

REFERENCE: National Engineering Handbook, Section 4, HYDROLOGY

RUNOFF FOR INCHES OF RAINFALL

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0										
1							0.00	0.00	0.01	0.02
2	0.03	0.04	0.06	0.08	0.09	0.12	0.14	0.16	0.19	0.22
3	0.25	0.28	0.31	0.34	0.38	0.42	0.45	0.49	0.53	0.58
4	0.62	0.66	0.71	0.75	0.80	0.85	0.90	0.95	1.00	1.05
5	1.11	1.16	1.21	1.27	1.33	1.38	1.44	1.50	1.56	1.62
6	1.68	1.74	1.80	1.86	1.93	1.99	2.05	2.12	2.18	2.25
7	2.31	2.38	2.45	2.52	2.58	2.65	2.72	2.79	2.86	2.93
8	3.00	3.07	3.15	3.22	3.29	3.36	3.44	3.51	3.59	3.66
9	3.73	3.81	3.88	3.96	4.04	4.11	4.19	4.27	4.34	4.42
10	4.50	4.58	4.65	4.73	4.81	4.89	4.97	5.05	5.13	5.21
11	5.29	5.37	5.45	5.53	5.61	5.69	5.78	5.86	5.94	6.02
12	6.10	6.19	6.27	6.35	6.44	6.52	6.60	6.69	6.77	6.85
13	6.94	7.02	7.11	7.19	7.28	7.36	7.45	7.53	7.62	7.70
14	7.79	7.88	7.96	8.05	8.13	8.22	8.31	8.39	8.48	8.57
15	8.66	8.74	8.83	8.92	9.00	9.09	9.18	9.27	9.36	9.44
16	9.53	9.62	9.71	9.80	9.89	9.98	10.06	10.15	10.24	10.33
17	10.42	10.51	10.60	10.69	10.78	10.87	10.96	11.05	11.14	11.23
18	11.32	11.41	11.50	11.59	11.68	11.77	11.86	11.95	12.04	12.13
19	12.22	12.31	12.41	12.50	12.59	12.68	12.77	12.86	12.95	13.04
20	13.14	13.23	13.32	13.41	13.50	13.59	13.69	13.78	13.87	13.96

NOTE: Runoff value determined by equation $Q = \frac{(P-0.2\,S)^2}{P+0.8\,S}$

REFERENCE: National Engineering Handbook, Section 4, HYDROLOGY

CURVE
56

RUNOFF FOR INCHES OF RAINFALL

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
21	13.83	13.92	14.02	14.11	14.20	14.29	14.38	14.48	14.57	14.66
22	14.75	14.84	14.94	15.03	15.12	15.21	15.31	15.40	15.49	15.58
23	15.68	15.77	15.86	15.96	16.05	16.14	16.24	16.33	16.42	16.51
24	16.61	16.70	16.79	16.89	16.98	17.07	17.17	17.26	17.36	17.45
25	17.54	17.64	17.73	17.82	17.92	18.01	18.11	18.20	18.29	18.39
26	18.48	18.58	18.67	18.76	18.86	18.95	19.05	19.14	19.24	19.33
27	19.42	19.52	19.61	19.71	19.80	19.90	19.99	20.09	20.18	20.28
28	20.37	20.46	20.56	20.65	20.75	20.84	20.94	21.03	21.13	21.22
29	21.32	21.41	21.51	21.60	21.70	21.79	21.89	21.98	22.08	22.18
30	22.27	22.37	22.46	22.56	22.65	22.75	22.84	22.94	23.03	23.13
31	23.22	23.32	23.42	23.51	23.61	23.70	23.80	23.89	23.99	24.09
32	24.18	24.28	24.37	24.47	24.56	24.66	24.76	24.85	24.95	25.04
33	25.14	25.24	25.33	25.43	25.52	25.62	25.72	25.81	25.91	26.01
34	26.10	26.20	26.29	26.39	26.49	26.58	26.68	26.78	26.87	26.97
35	27.06	27.16	27.26	27.35	27.45	27.55	27.64	27.74	27.84	27.93
36	28.03	28.13	28.22	28.32	28.42	28.51	28.61	28.71	28.80	28.90
37	29.00	29.09	29.19	29.29	29.38	29.48	29.58	29.67	29.77	29.87
38	29.96	30.06	30.16	30.25	30.35	30.45	30.54	30.64	30.74	30.84
39	30.93	31.03	31.13	31.22	31.32	31.42	31.51	31.61	31.71	31.81
40	31.90	32.00	32.10	32.19	32.29	32.39	32.49	32.58	32.68	32.78

NOTE: Runoff value determined by equation $Q = \dfrac{(P-0.2\,S)^2}{P+0.8\,S}$

REFERENCE: National Engineering Handbook, Section 4, HYDROLOGY

CURVE 56

RUNOFF FOR INCHES OF RAINFALL

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0										
1							0.00	0.00	0.01	0.01
2	0.02	0.03	0.05	0.06	0.08	0.10	0.12	0.14	0.17	0.19
3	0.22	0.25	0.28	0.31	0.34	0.38	0.42	0.45	0.49	0.53
4	0.57	0.62	0.66	0.70	0.75	0.79	0.84	0.89	0.94	0.99
5	1.04	1.09	1.15	1.20	1.25	1.31	1.36	1.42	1.48	1.54
6	1.60	1.66	1.72	1.78	1.84	1.90	1.96	2.02	2.09	2.15
7	2.22	2.28	2.35	2.41	2.48	2.55	2.62	2.68	2.75	2.82
8	2.89	2.96	3.03	3.10	3.17	3.25	3.32	3.39	3.46	3.54
9	3.61	3.68	3.76	3.83	3.91	3.98	4.06	4.13	4.21	4.28
10	4.36	4.44	4.51	4.59	4.67	4.75	4.83	4.90	4.98	5.06
11	5.14	5.22	5.30	5.38	5.46	5.54	5.62	5.70	5.78	5.86
12	5.95	6.03	6.11	6.19	6.27	6.36	6.44	6.52	6.60	6.69
13	6.77	6.85	6.94	7.02	7.11	7.19	7.27	7.36	7.44	7.53
14	7.61	7.70	7.78	7.87	7.95	8.04	8.13	8.21	8.30	8.38
15	8.47	8.56	8.64	8.73	8.82	8.90	8.99	9.08	9.16	9.25
16	9.34	9.43	9.52	9.60	9.69	9.78	9.87	9.96	10.04	10.13
17	10.22	10.31	10.40	10.49	10.58	10.67	10.75	10.84	10.93	11.02
18	11.11	11.20	11.29	11.38	11.47	11.56	11.65	11.74	11.83	11.92
19	12.01	12.10	12.19	12.28	12.37	12.46	12.55	12.65	12.74	12.83
20	12.92	13.01	13.10	13.19	13.28	13.37	13.47	13.56	13.65	13.74

NOTE: Runoff value determined by equation $Q = \frac{(P-0.2\,S)^2}{P+0.8\,S}$

REFERENCE: National Engineering Handbook, Section 4, HYDROLOGY

RAINFALL-RUNOFF DEPTHS FOR SELECTED RUNOFF CURVE NUMBERS

Inches \ Tenths	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	0.00	0.01	0.07	0.15	0.23	0.32	0.41	0.51	0.60	0.69
1	0.79	0.89	0.99	1.09	1.19	1.28	1.38	1.48	1.58	1.68
2	1.78	1.88	1.98	2.08	2.18	2.27	2.37	2.47	2.57	2.67
3	2.77	2.87	2.97	3.07	3.17	3.27	3.37	3.47	3.57	3.67
4	3.77	3.87	3.97	4.07	4.17	4.27	4.37	4.47	4.57	4.67
5	4.77	4.87	4.97	5.07	5.17	5.27	5.37	5.47	5.57	5.67
6	5.77	5.87	5.97	6.07	6.17	6.27	6.37	6.47	6.57	6.67
7	6.77	6.87	6.98	7.07	7.17	7.27	7.37	7.47	7.57	7.67
8	7.76	7.86	7.96	8.06	8.16	8.26	8.36	8.46	8.56	8.66
9	8.76	8.86	8.96	9.06	9.16	9.26	9.36	9.46	9.56	9.66
10	9.76	9.86	9.96	10.06	10.16	10.26	10.36	10.46	10.56	10.66
11	10.76	10.86	10.96	11.06	11.16	11.26	11.36	11.46	11.56	11.66
12	11.76	11.86	11.96	12.06	12.16	12.26	12.36	12.46	12.56	12.66

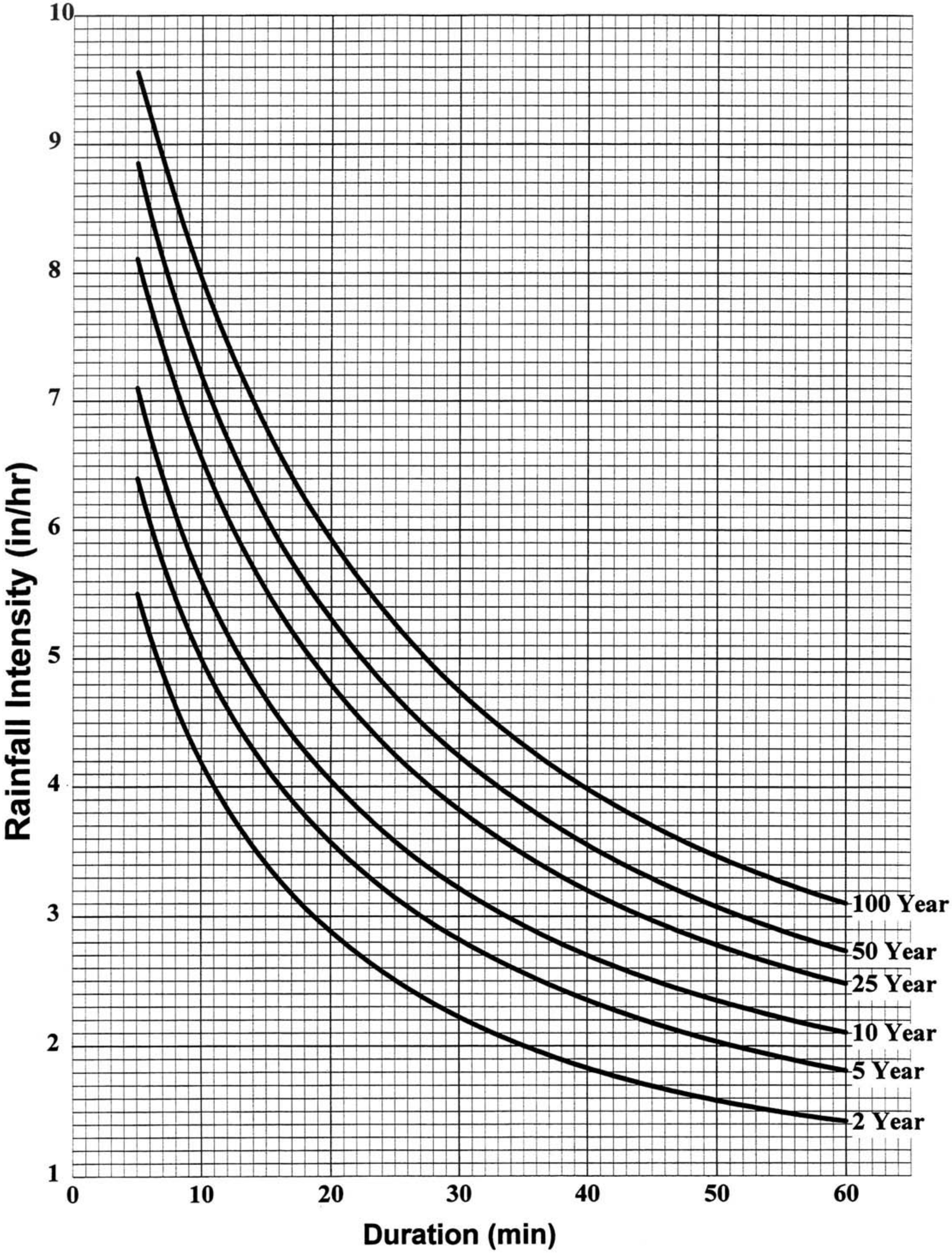
CURVE
98

Exhibit 2-7A

REFERENCE	U. S. DEPARTMENT OF AGRICULTURE	TSC - NE - ENG.
SCS TR-16	SOIL CONSERVATION SERVICE ENGINEERING & WATERSHED PLANNING UNIT BROOMALL, PENNSYLVANIA	220 SHEET 14 OF 14

APPENDIX 4D

I - D - F Curves for Virginia



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Rainfall Intensity (in/hr)
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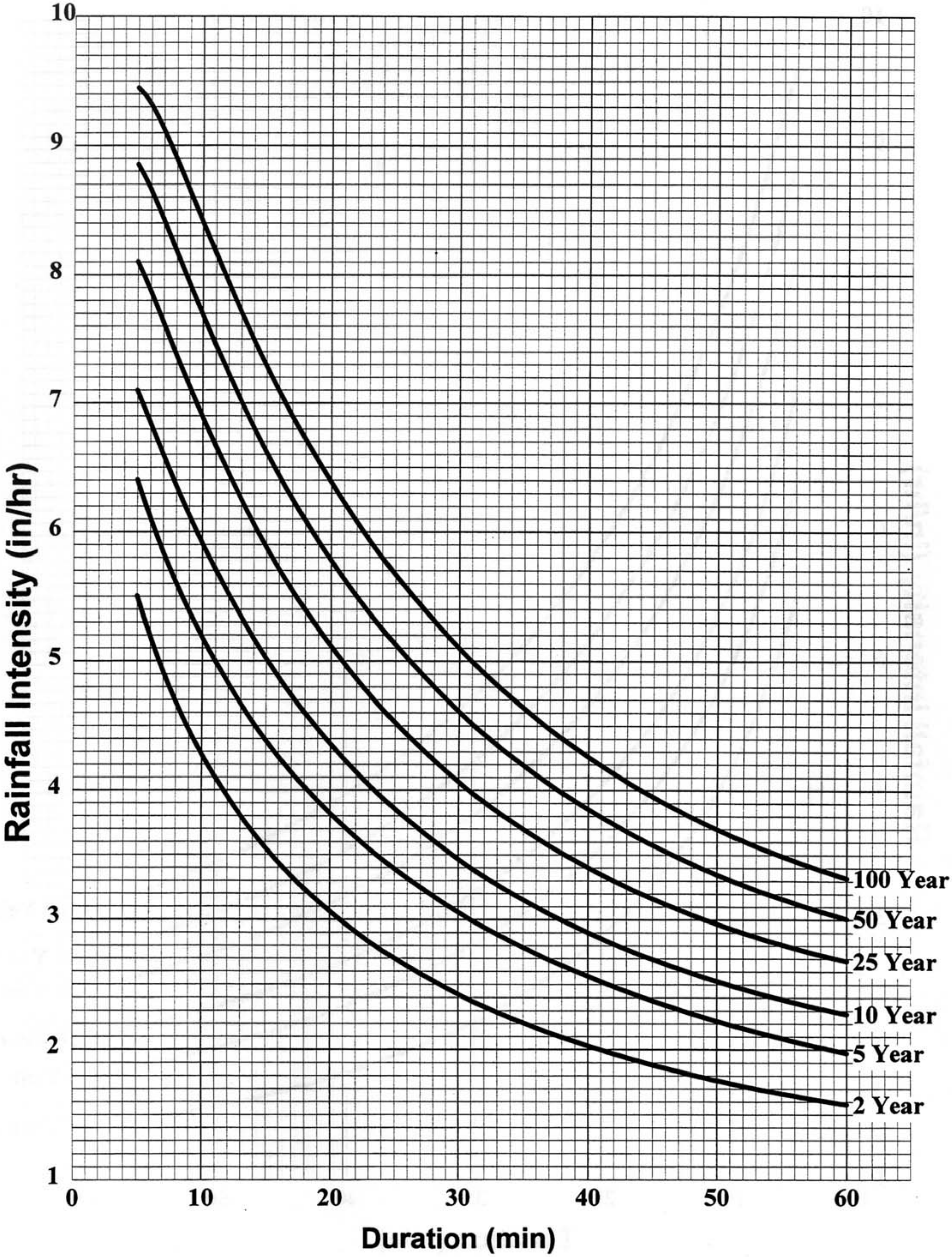

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Duration (min)
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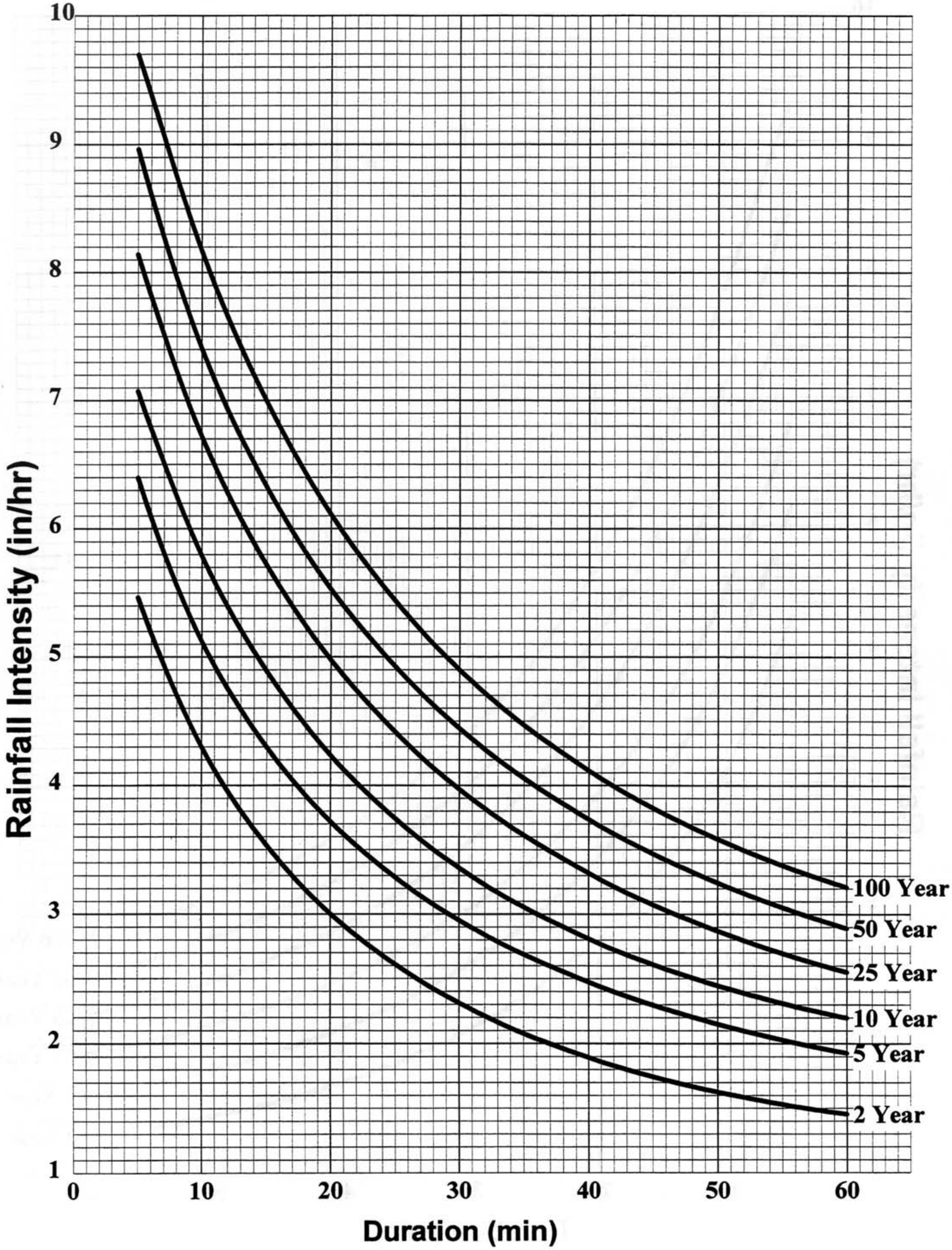
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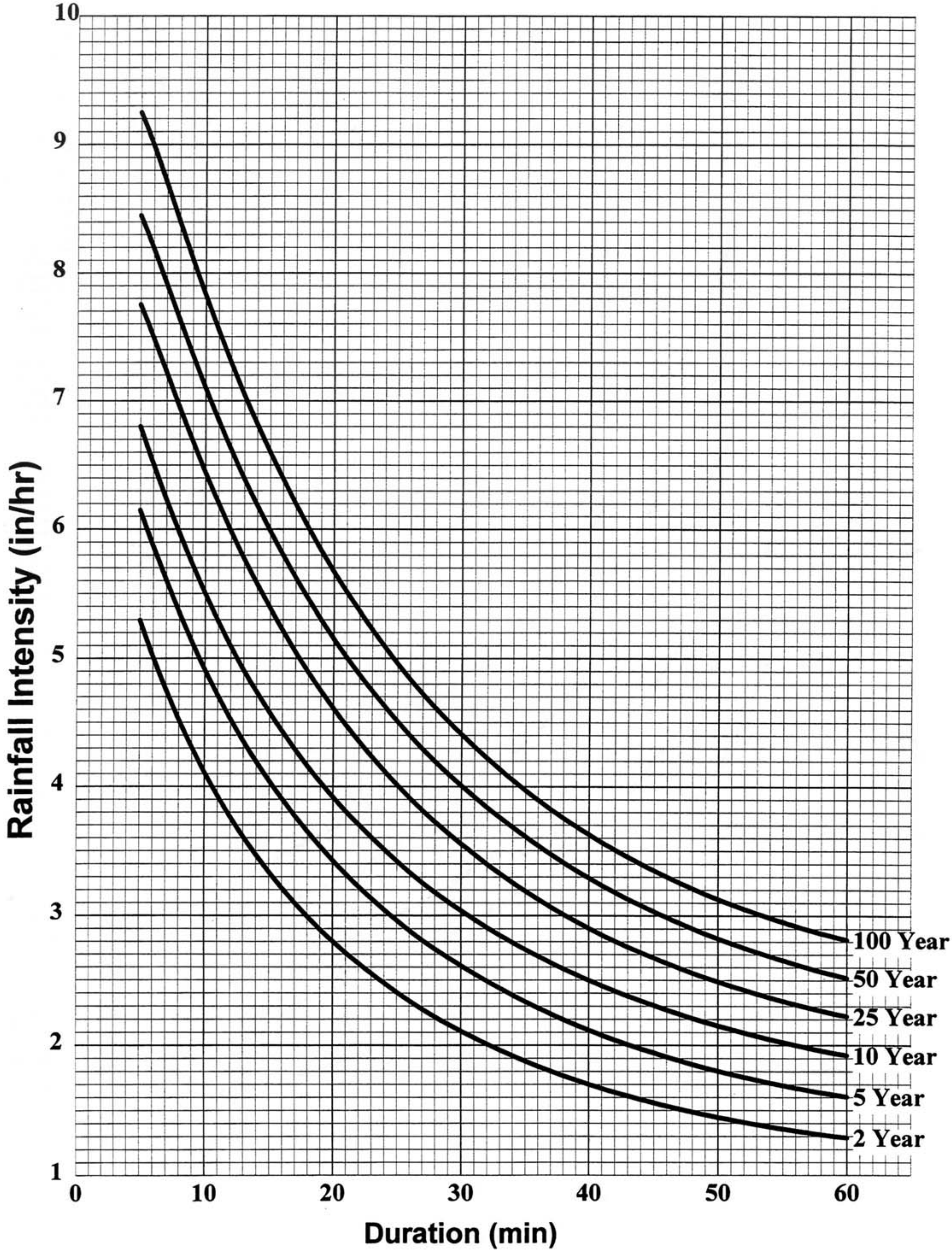
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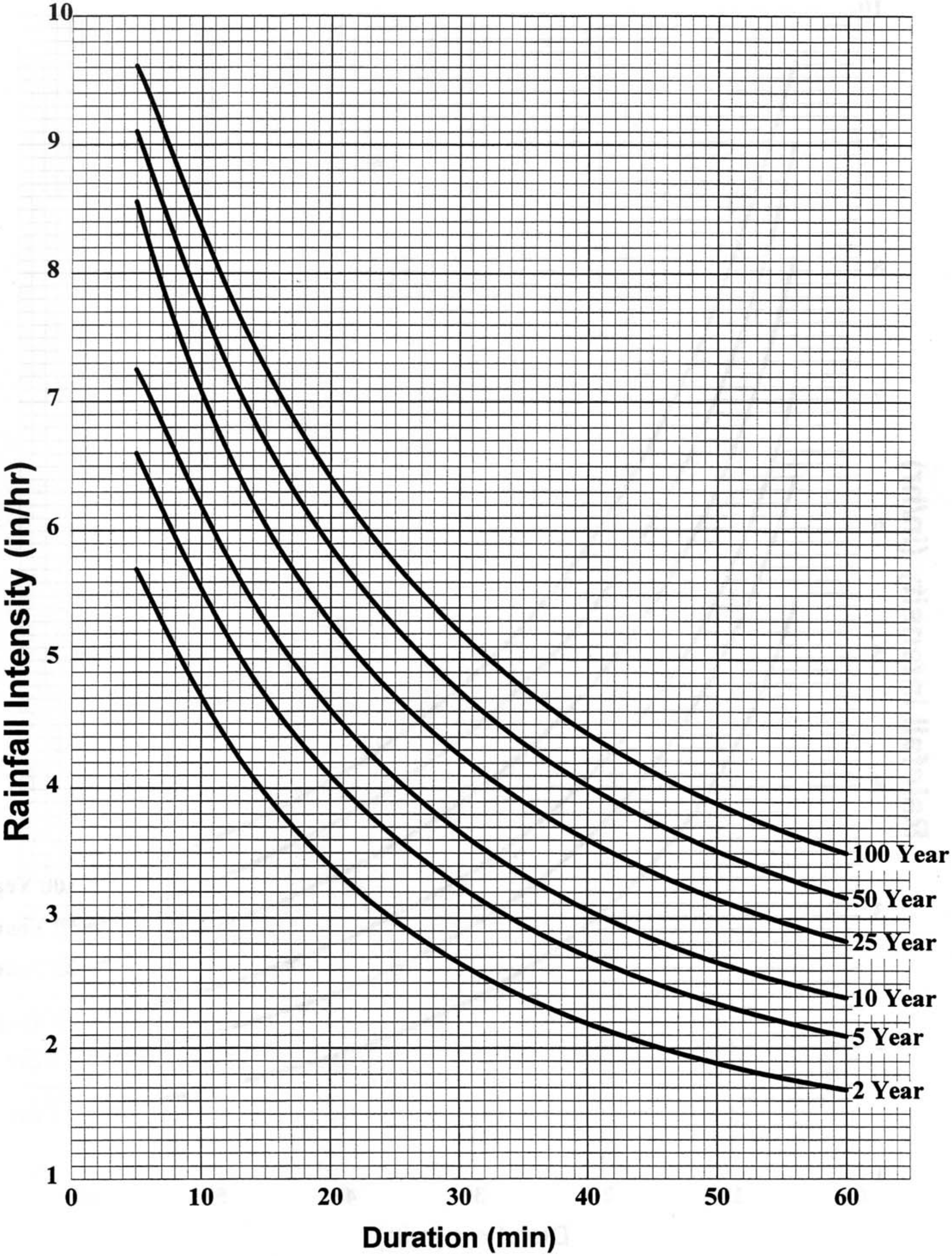
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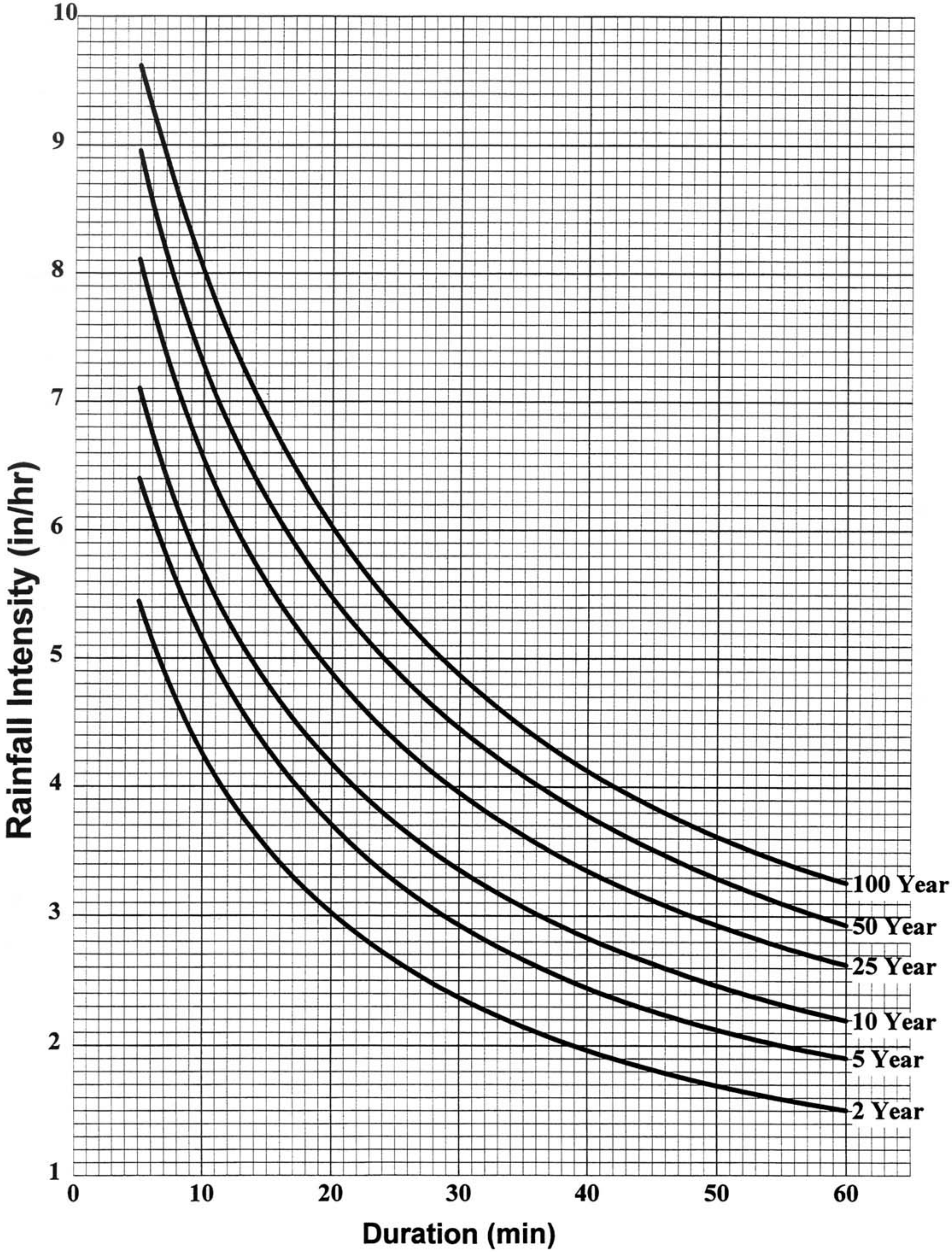
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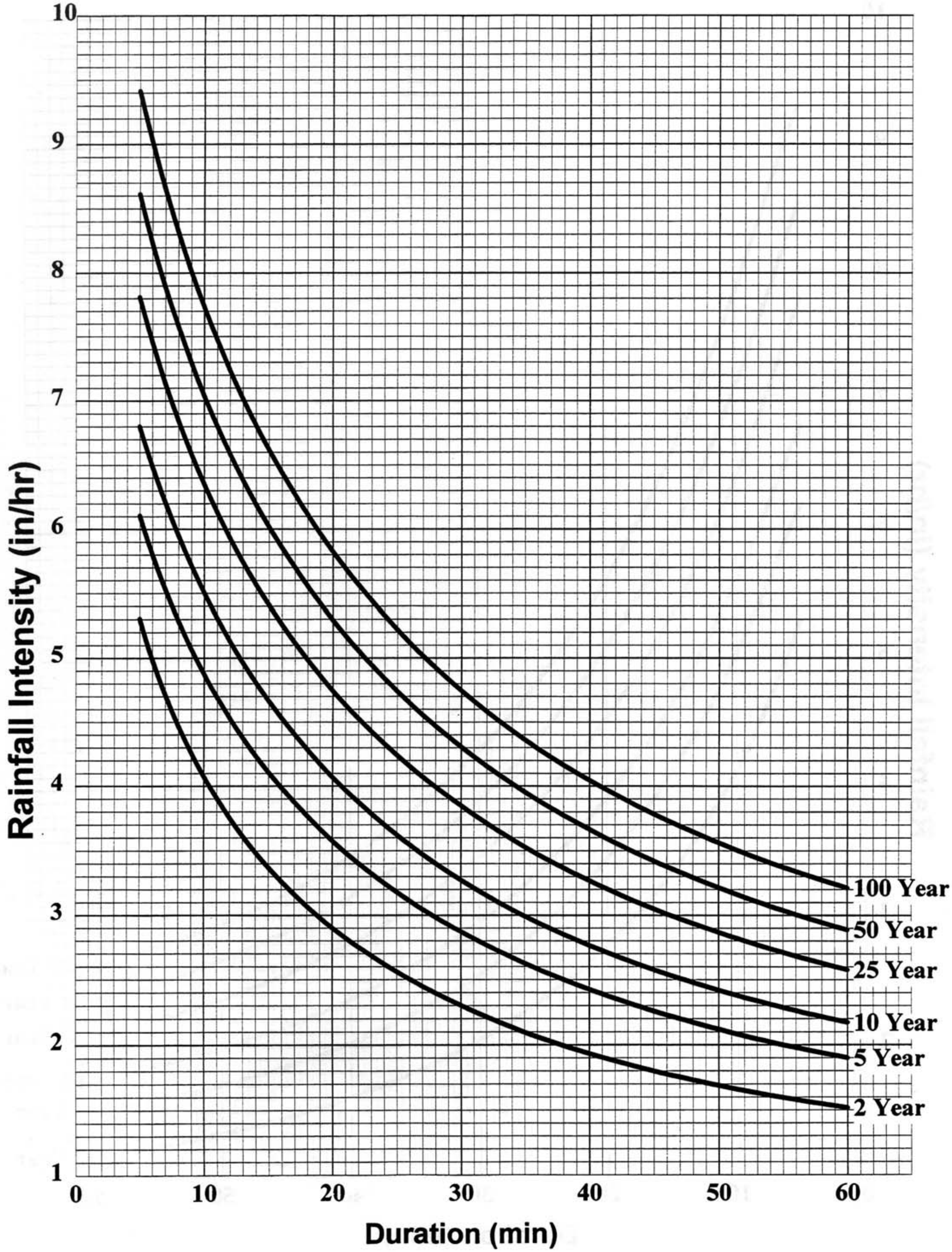
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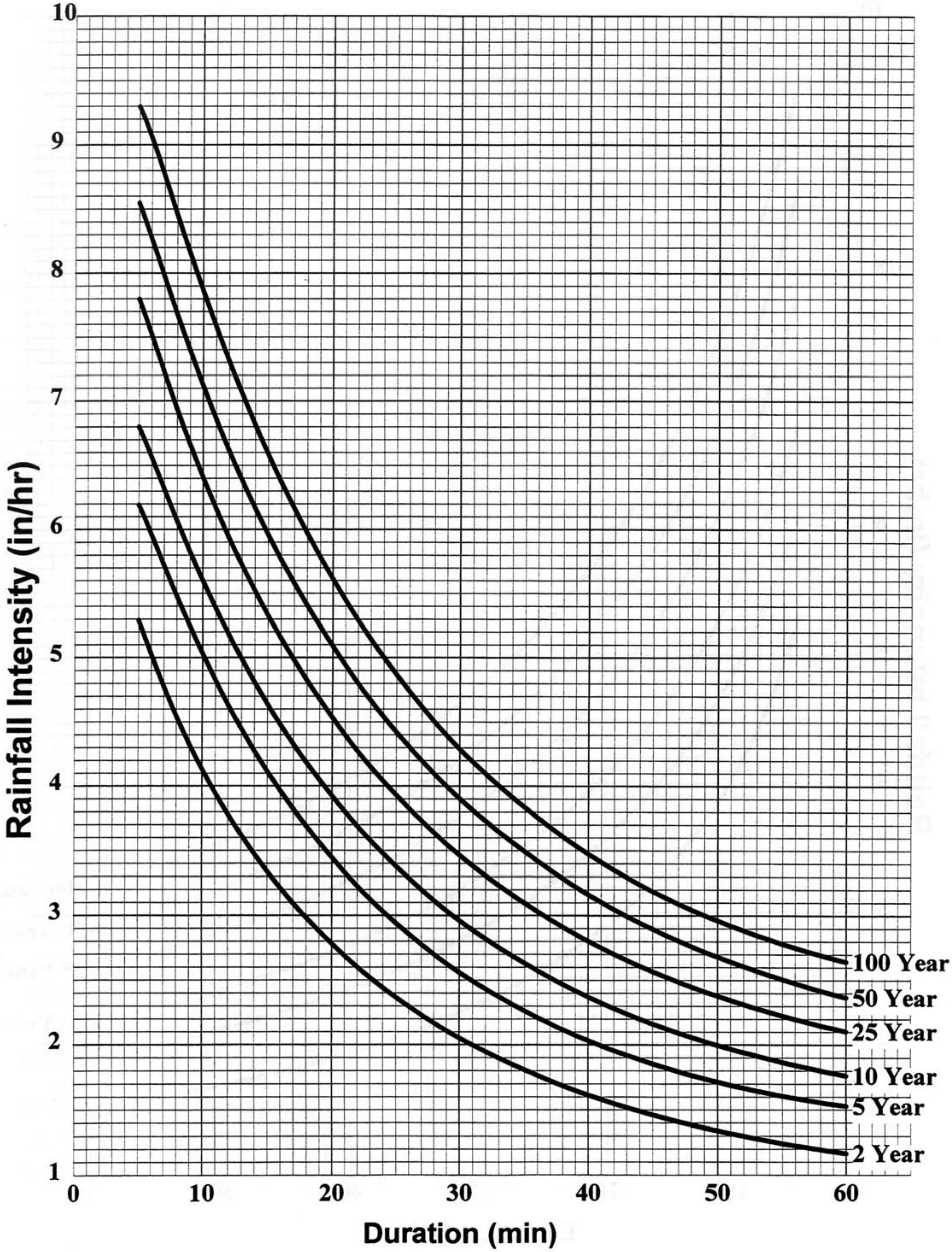
Rainfall Intensity (in/hr)
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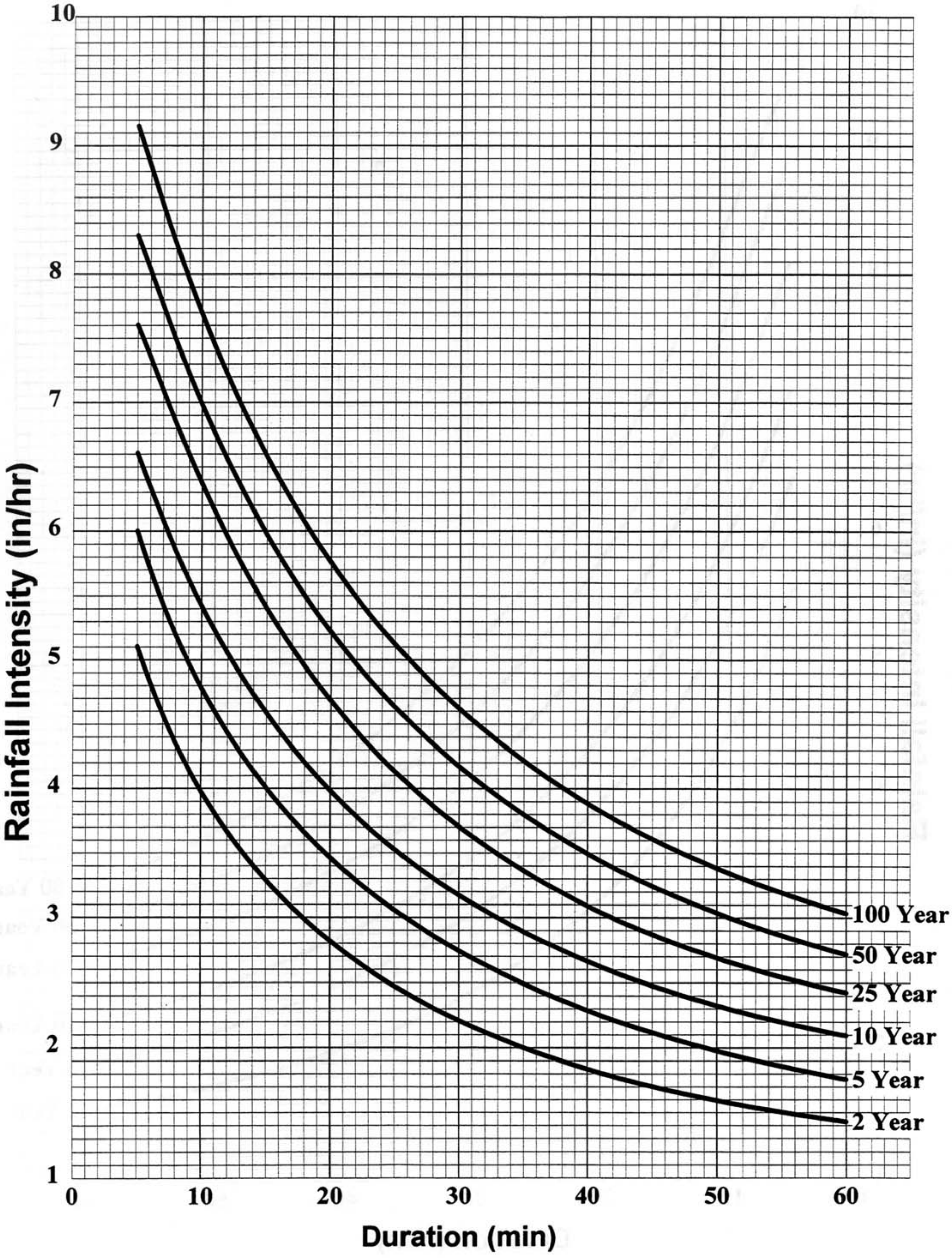
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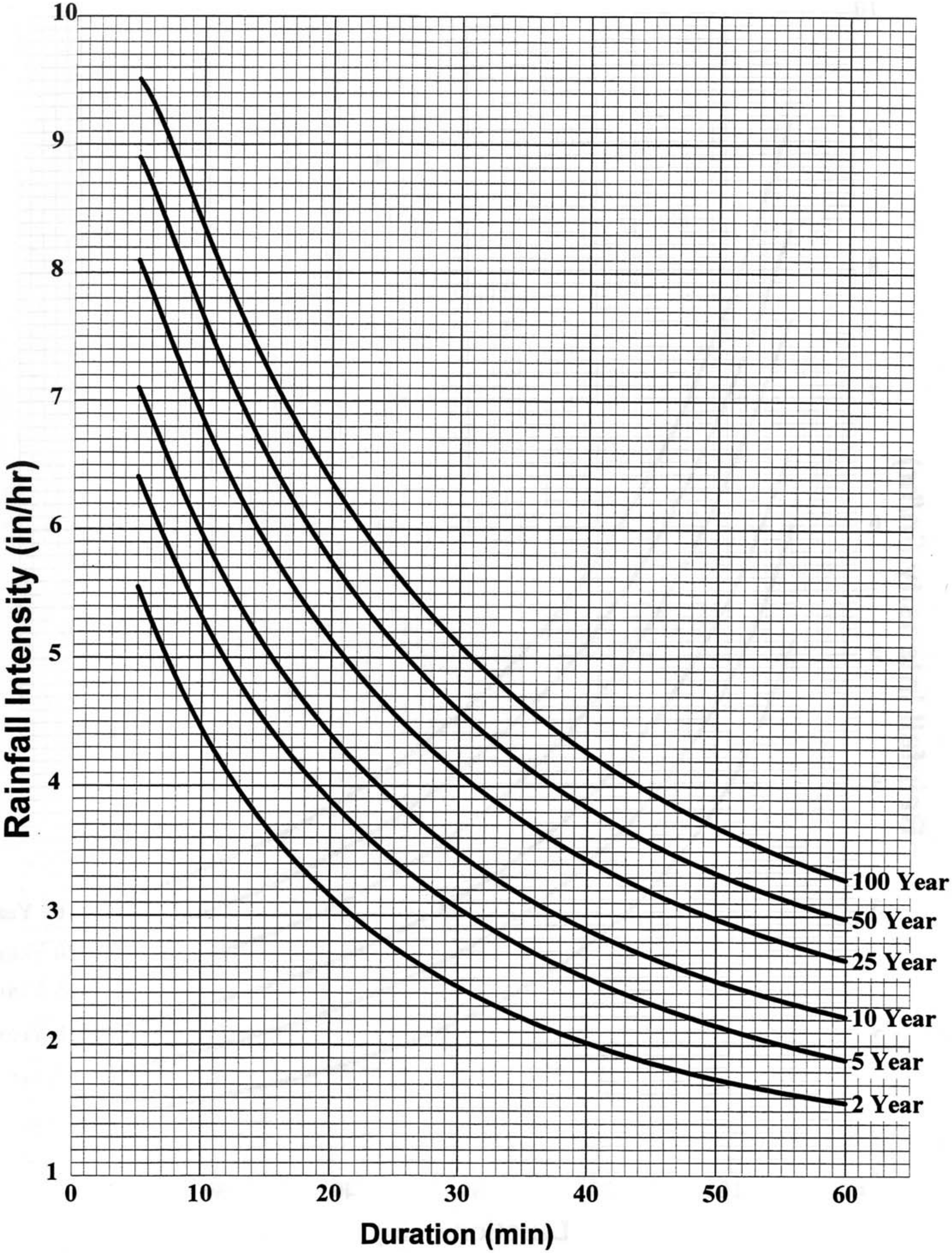
Rainfall Intensity (in/hr)
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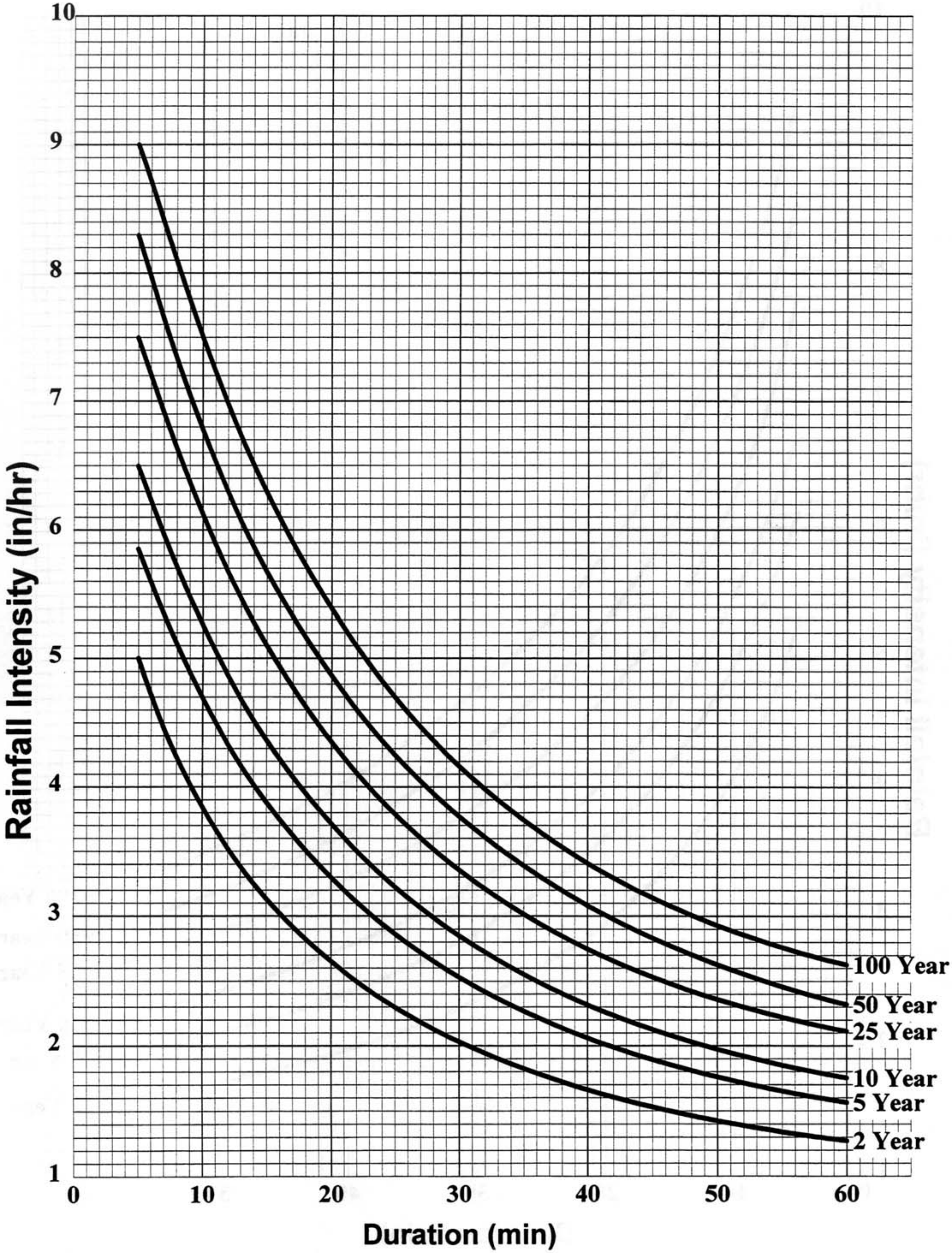
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Rainfall Intensity (in/hr)
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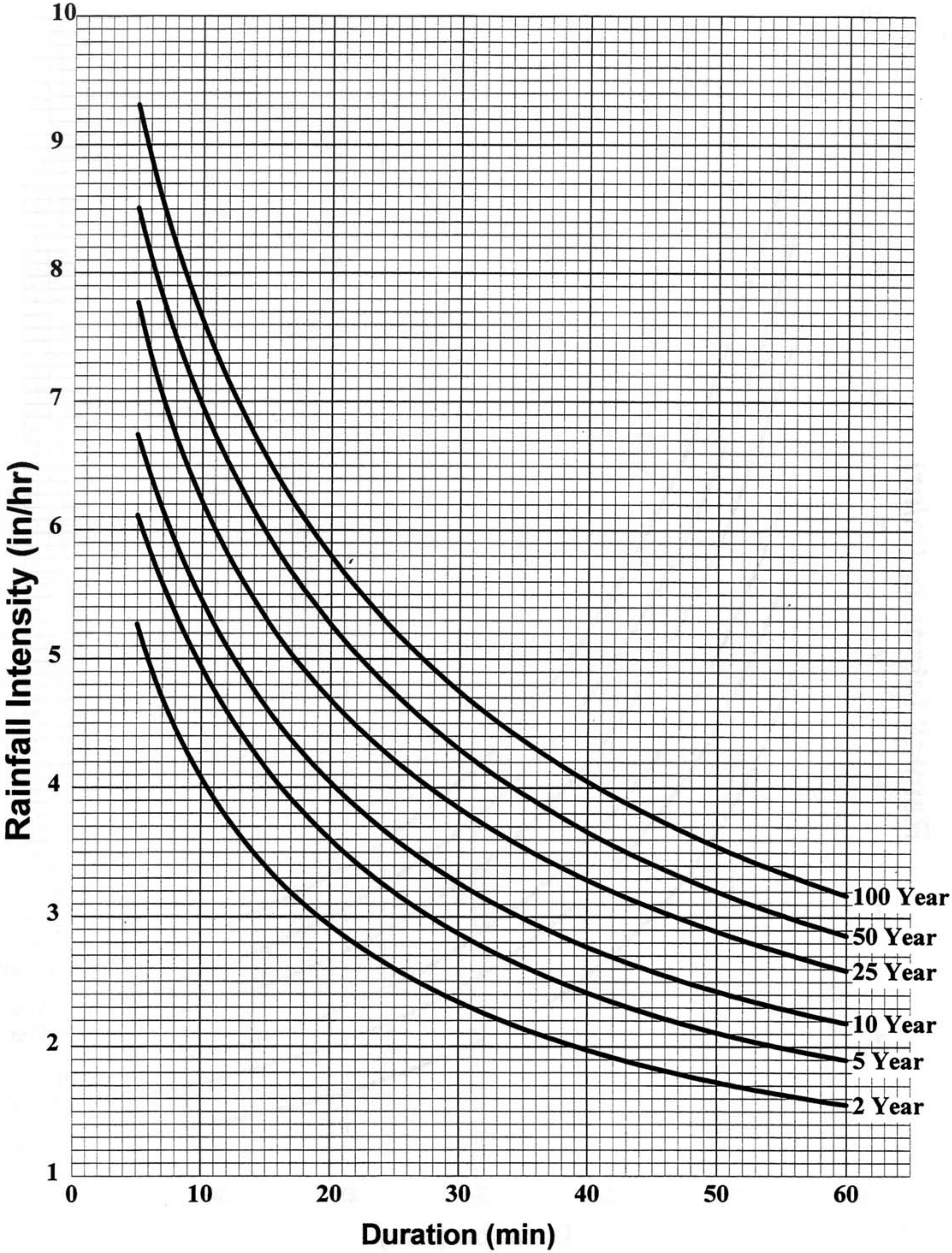
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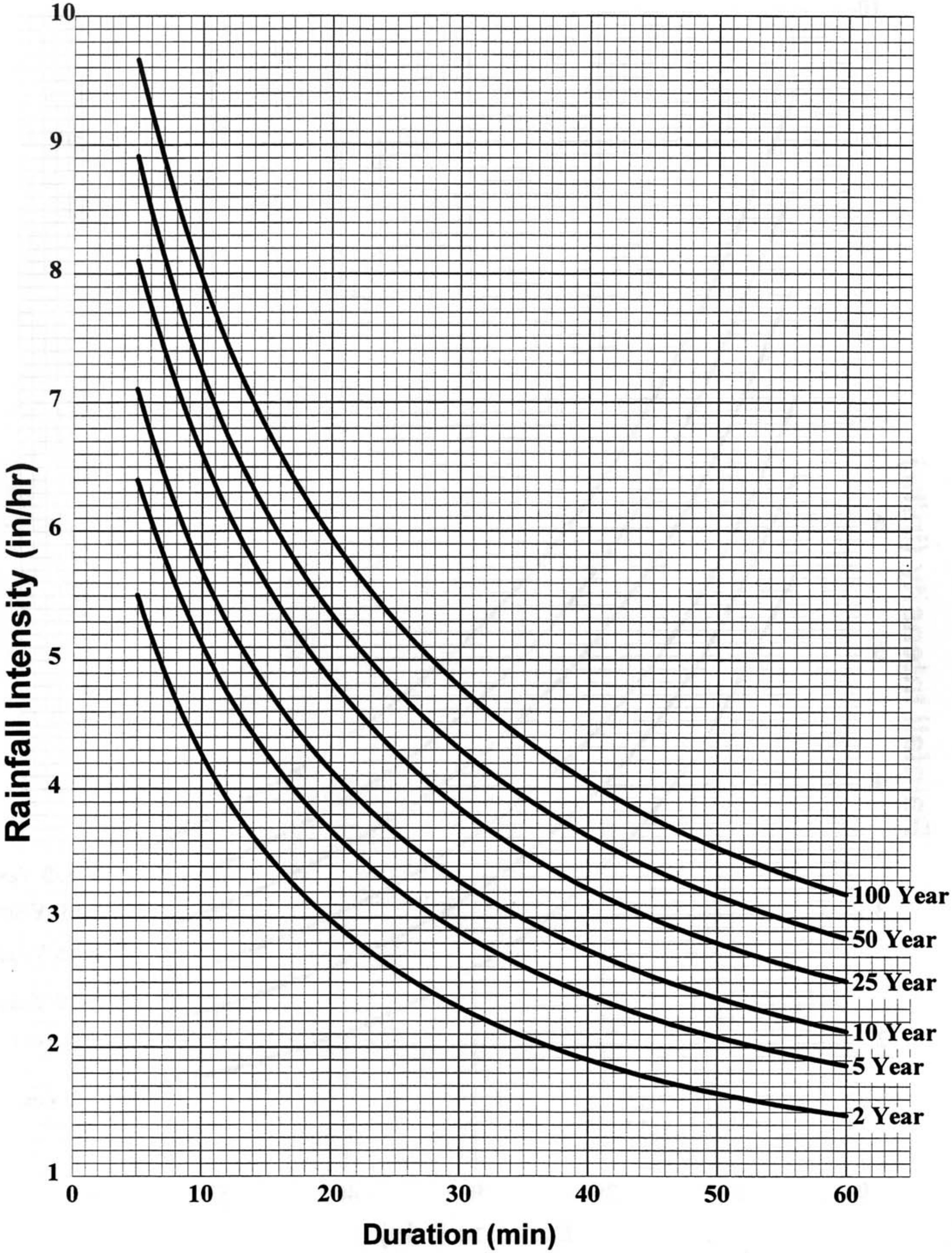
Rainfall Intensity (in/hr)
Duration (min)
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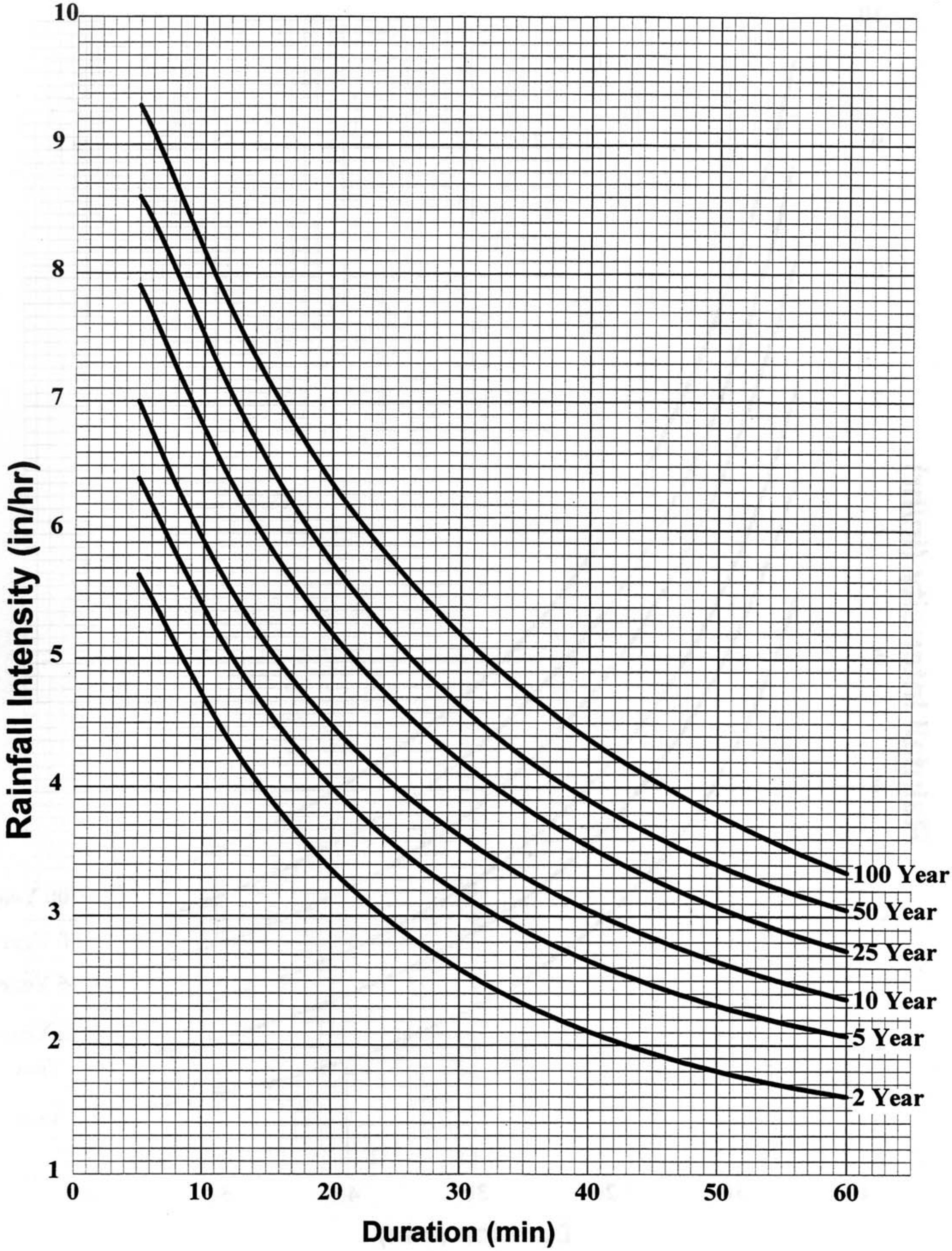

Rainfall Intensity (in/hr)
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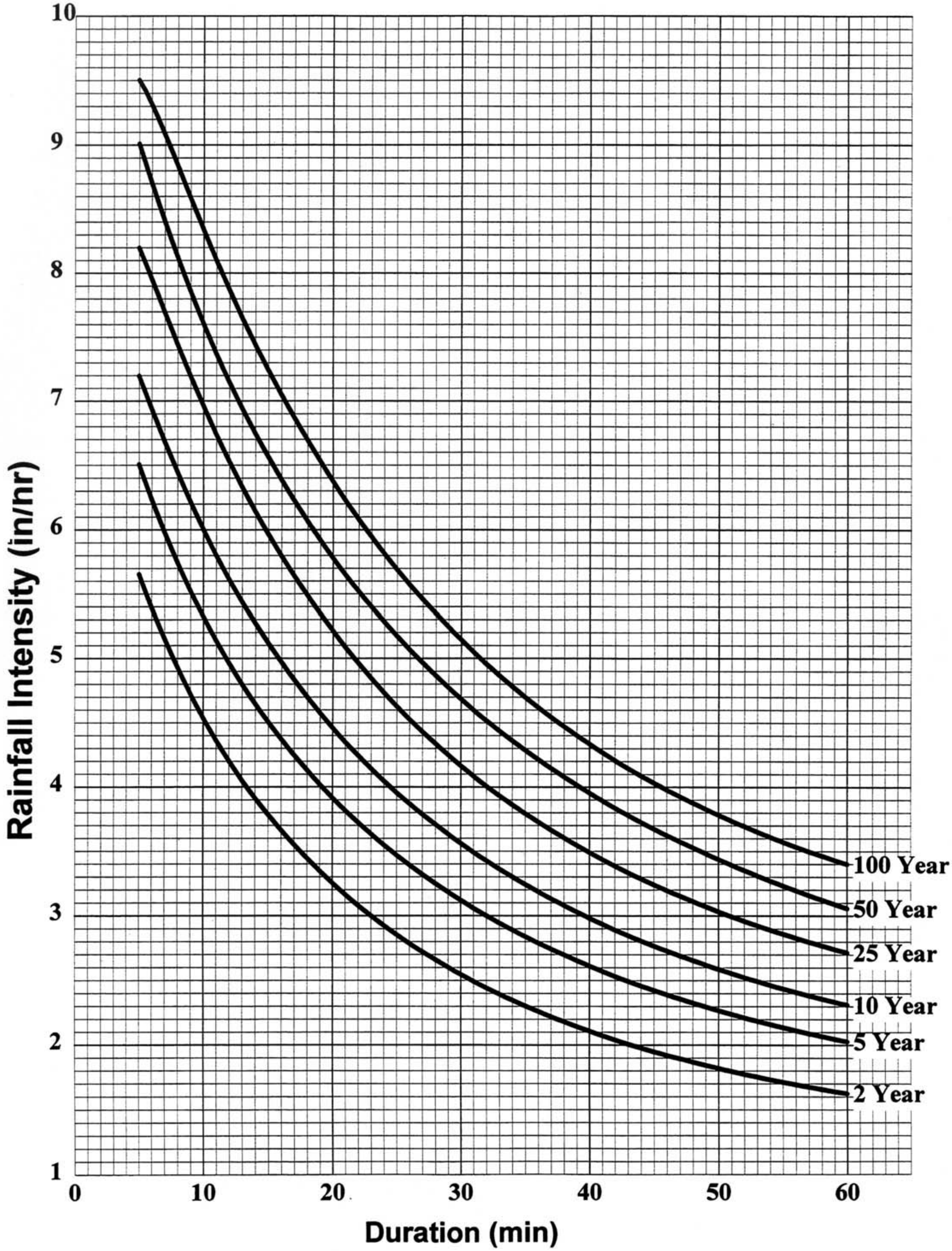
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